(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 0 862 285 A2

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
02.09.1998 Bulletin 1998/36

(51) Int. Cl.[6]: H04B 10/18

(21) Application number: 97116632.7

(22) Date of filing: 24.09.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV RO SI

(30) Priority: 27.02.1997 JP 44407/97

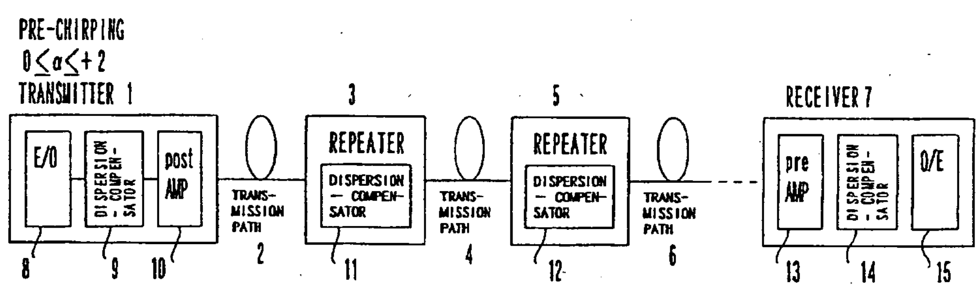
(71) Applicant: FUJITSU LIMITED
Kawasaki-shi, Kanagawa 211-8588 (JP)

(72) Inventors:
- Miyauchi, Akira
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Yamane, Kazuo
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Kawasaki, Yumiko
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Okano, Satoru,
  c/o Fujitsu H. D. Techn. Ltd.
  Sapporo-shi, Hokkaido 060 (JP)

(74) Representative:
von Fischern, Bernhard, Dipl.-Ing. et al
Hoffmann - Eitle,
Patent- und Rechtsanwälte,
Arabellastrasse 4
81925 München (DE)

(54) **Optical transmission system using in-line amplifiers**

(57) In a system connecting a transmitter and a receiver using transmission paths and repeaters (in-line amplifiers), red chirping whose α parameter is positive is performed for an optical signal on a transmitting side. Each of the repeaters includes a dispersion-compensator for compensating the amount of dispersion on a preceding transmission path. The amount of dispersion compensation of the dispersion-compensator included in the transmitter is made constant. The dispersion-compensator included in the receiver is arranged in order to compensate the amount of dispersion on a preceding transmission path. A spread of a pulse width on a transmission path can be efficiently compensated by using the compensation capability of the dispersion-compensators and the red chirping on the transmitting side.



α PARAMETER : $0 \leq \alpha \leq +2$
AMOUNT OF DISPERSION COMPENSATION TRANSMITTING SIDE : CONSTANT VALUE
REPEATER : TOTAL AMOUNT OF DIPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)
RECEIVING SIDE : TOTAL AMOUNT OF DISPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)

F I G. 2

EP 0 862 285 A2

Description

Background of the Invention

Field of the Invention

The present invention relates to an optical transmission system using fibers, and more particularly to an optical transmission system using in-line amplifiers.

Description of the Related Art

An optical transmission system is now being developed in order to increase its capacity and extend its span of transmission. An increase of a bit rate or a wavelength division multiplexing system are now being discussed so as to increase its capacity. In the meantime, an optical amplifier is introduced so as to extend its span of transmission. The optical amplifier includes a post-amplifier (for strengthening output of transmission power), a pre-amplifier (for increasing the sensitivity of reception power), and a repeater (in-line amplifier). The optical amplifier is currently under development at a production level. The introduction of the optical amplifier allows the difference between the levels of optical intensities of transmission and reception to be extended, and an allowable loss of fiber is increased.

Especially, a system configuration using a post-amplifier and a pre-amplifier has been put into practical use. Additionally, the in-line amplifier is under development in order to extend the reproduction relay interval. Here, the in-line amplifier is a repeater which amplifies an optical signal unchanged without converting it into an electric signal, and transmits the amplified signal.

The system using in-line amplifiers, however, poses a new problem where amplified spontaneous emission lights occurring in a plurality of amplifiers, due to the connection of the plurality of amplifiers, are accumulated, and the S/N ratio is lowered. The lowering of the S/N ratio leads to the degradation of a minimum reception power of a receiver. To obtain a predetermined system gain in consideration of this degradation, transmission power output must be strong thereby a lower limit value of the transmission power is determined. Furthermore, if the transmission power output is stronger (+8dBm for a dispersion shifted fiber, and 10dBm or more for a single mode fiber, although it depends on the length of a transmission path or a wavelength), the waveform is significantly degraded due to the non-linear effect of a fiber. One type of wavelength degradation is an optical Kerr effect (refractive index changes depending on an optical intensity). This is a phenomenon where a frequency (wavelength) shift occurs at the rising and falling edges of an optical signal pulse (SPM: Self- Phase Modulation). Even if the width of an optical wavelength of the signal before being transmitted is narrow in this case, the width of the wavelength increases, and at the same time, a reception waveform significantly changes due to the influence of fiber dispersion. That is, the upper limit value of the optical transmission power is determined in consideration of such an influence.

The fiber dispersion means that the speed of light propagating a fiber depends on its wavelength. An optical pulse having a certain wavelength width is widened or compressed after fiber propagation. This effect is referred to as the fiber chromatic dispersion. Accordingly, a reception waveform in an optical transmission system after the fiber propagation varies depending on the chromatic dispersion, and a transmission error will occur depending on the degree of dispersion. Therefore, the fiber dispersion imposes a restriction on a transmission distance.

With a system using an in-line amplifier which amplifies an optical signal unchanged, such non-linear effect and dispersion are accumulated while the optical signal travels. Accordingly, it becomes quite impossible to properly receive the optical signal on a receiving side unless suitable compensation is made.

In the meantime, a system implemented by combining blue chirping on a transmitting side and dispersion compensation in repeaters and a receiver was conventionally proposed.

Fig.1 is a schematic diagram showing a combination of conventional pre-chirping and a dispersion compensator.

In this figure, a transmitter 1000 and a receiver 1010 are connected by transmission paths 1003, 1006 and 1009, and repeaters 1004 and 1007. The transmitter 1000 is composed of an E/O 1001, for converting an electric signal into an optical signal, and a post-amplifier 1002. The transmitter 1000 performs blue-chirping for the optical signal, and transmits the signal. The transmitted optical signal travels along the transmission path 1003 and enters the repeater 1004. The repeater 1004 amplifies the optical signal, and performs dispersion compensation using the dispersion compensator 1005. The amount of dispersion compensation is a constant value. The optical signal, which is further amplified and dispersion-compensated, passes along the transmission path 1006 and enters the repeater 1007. The repeater 1007 also amplifies the signal, performs dispersion compensation and transmits the signal to the transmission path 1009. The optical signal passes through repeaters whose number is predetermined, until it reaches the receiver 1010. The receiver 1010 amplifies the received optical signal using a pre-amplifier, performs dispersion compensation using a dispersion-compensator 1012, inputs the signal to an O/E 1013 in order to convert the optical signal into an electric signal, and extracts necessary data.

That is, the conventional combination is implemented by combining the blue chirping (especially, chirping parameter α=-1) as the pre-chirping, and the compensation by the dispersion-compensators arranged in the in-line amplifiers and the receiver

(between the pre-amplifier and the O/E). If the blue-chirping is performed in a fiber of + dispersion, an output pulse is compressed due to the characteristics of the fiber of + dispersion and the chirping. As a result, a transmission distance is made relatively longer. Especially, in a system which does not use optical amplifiers, an optical signal having the wavelength 1.5μm is more effective when it travels along a single mode fiber (1.3μm zero-dispersion). Accordingly, the dispersion compensation implemented by combining the pre-chirping and the succeeding compensation was considered to be also effective in a system using optical amplifiers. If the amount of dispersion compensation is set in order to keep a residual dispersion value (obtained by subtracting the amount of dispersion compensation from a total amount of dispersion of a transmission fiber) constant, a stable transmission characteristic can be obtained.

However, if output of the transmission power is increased by introducing optical amplifiers according to this method, the influence of the non-linear effect of an optical fiber remarkably appears. The influence of the non-linear effect is equivalent to the characteristic of the blue chirping. The pulse width of the transmission waveform is narrowed due to the influence of the pre-chirping of the transmitter and the non-linear effect of the optical fiber. As a result, the influence of the non-linear effect remarkably appears, and the waveform is significantly changed for the dispersion.

The problems posed by the method for performing the blue-chirping at the time of transmission are listed below.

1) Output of transmission power cannot be increased.
2) Dispersion-compensation on a transmitting side is ineffective.
3) The dispersion-compensation is performed in in-line amplifiers and on a receiving side due to the ineffectivity on the transmitting side in consideration with 2). Accordingly, the losses of dispersion-compensators become larger, and the tolerance of the losses becomes difficult as transmission distance is extended. Lowering the level of an optical input to the O/E leads to the degradation of reception sensitivity, and imposes a limitation. Furthermore, optical input power may sometimes have an upper limit depending on the dispersion-compensator to be used.
4) The tolerance of the amount of dispersion-compensation which can ensure the transmission characteristic is small.
5) The number of menus increases when menus of a dispersion-compensator according to a transmission distance are set as a product due to the small tolerance as a result of 4).

Summary of the Invention

The object of the present invention is to provide a technology which can compensate transmission degradation especially due to fiber dispersion, and ensure a transmission characteristic of a longer distance, in an optical in-line amplifier system.

The optical transmission system according to the present invention assumes the use of repeaters (in-line amplifiers). It comprises a transmitter, repeaters, a receiver and transmission paths for interconnecting these modules. The present invention is characterized in that the transmitter performs chirping whose α parameter is positive for an optical signal and each of the repeaters and the receiver include a dispersion-compensator having an amount of dispersion compensation for compensating dispersion of a transmission path preceding each of the repeaters and the receiver.

Since the non-linear effect that the optical signal receives on a transmission path corresponds to the blue chirping, this effect can be compensated by performing red chirping whose α parameter is positive on a transmitting side. This leads to the effect of preventing the waveform of the optical signal to be degraded.

Furthermore, the degradation of the optical signal can be prevented more effectively by setting the amount of dispersion compensation in order to compensate the dispersion of a preceding transmission path in each of the repeaters or the receiver.

With the above described configuration, an optical signal can be transmitted by performing the red chirping compensating the non-linear effect in order to prevent a waveform to be degraded even if an optical output is made higher on a transmitting side.

Additionally, since a menu of the amount of dispersion compensation in a repeater or a receiver can be constructed by a combination of unit modules, its implementation as a product is relatively easy.

Brief Description of the Drawings

Fig.1 is a schematic diagram showing a combination of a conventional pre-chirping and dispersion-compensators;

Fig.2 is a schematic diagram showing the basic configuration of an embodiment according to the present invention;

Figs.3A and 3B are schematic diagrams showing the dependency of a 1R transmittable distance range corresponding to a change of an α parameter;

Figs.4A and 4B exemplify a menu setting at the time of propagation along a single mode fiber;

Fig.5 is a schematic diagram showing a dispersion compensation method and the degradation of a waveform on a receiving side when a 1R interval varies depending on a period at the time of the propagation along a single mode fiber;

Fig.6 is a graph showing the number of 1Rs satisfying a transmission characteristic required for an amount of dispersion compensation on a transmitting side, which is obtained for each α parameter;

Fig.7 is a schematic diagram showing the relationship of a 1R interval to an amount of a 1R residual dispersion;

Figs.8A through 8D are schematic diagrams explaining unit modules of a dispersion-compensator;

Figs.9A and 9B exemplify the structure of an optical switch for use in a unit module of the dispersion-compensator; and

Figs.10A through 10C exemplify the structures for compensating dispersion other than a dispersion-compensating fiber.

Description of the Preferred Embodiments

Fig.2 is a schematic diagram showing the basic configuration of an optical transmission system according to an embodiment of the present invention.

In this figure, a transmitter 1 and a receiver 7 are connected by transmission paths 2, 4, 6,... and repeaters 3, 5,.... The transmitter 1 is composed of an E/O (Electric-to-optical signal converter) 8, a dispersion-compensator 9 and a post-amplifier 10. The E/O 8 is intended to convert an electric signal into an optical signal. The dispersion-compensator is intended to perform a predetermined amount of dispersion compensation on the side of the transmitter 1. The post-amplifier 10 is intended to amplify an optical output in order to allow the optical signal to be transmitted farther along a transmission path. In addition, red chirping whose α parameter ranges between 0 and +2 is performed on the side of the transmitter 1, according to the present invention. The amount of dispersion compensation of each of the dispersion-compensators 11 and 12 included in the repeaters 3 or 5 is adjusted in order to compensate the dispersion of the preceding transmission path (transmission path from the preceding repeater to the local repeater: the length of a transmission path between repeaters is referred to as a 1R transmission distance or a 1R interval). That is, the dispersion-compensator 11 possesses the amount of dispersion compensation necessary for compensating the dispersion of the transmission path 2, while the dispersion-compensator 12 possesses the amount of dispersion compensation necessary for compensating the dispersion of the transmission path 4. Also dispersion-compensators arranged in other repeaters, (not shown in this figure) are configured so that they possess the amount of dispersion compensation necessary for compensating the dispersion of a preceding transmission path. The receiver 7 is composed of a pre-amplifier 13, a dispersion-compensator 14, and an O/E (optical-to-electric signal converter) 15. The pre-amplifier 13 is intended to amplify a transmitted optical signal so that it can be detected with ease. The dispersion-compensator 14 is arranged in order to compensate the dispersion of the transmission path preceding the receiver 7. The O/E 15 is intended to convert an optical signal into an electric signal, and output the converted signal to a device for extracting data.

A transmitting side narrows the pulse width of the signal using the characteristics of transmission chirping and dispersion-compensation on the transmitting side, and outputs the signal having a narrow pulse width to a transmission path. The signal is influenced by the non-linear effect of a fiber (narrowing of the pulse width) and the dispersion of the fiber (widening of the pulse width). Since the, reciprocal effects of the influences are to be cancelled out by each other, a slight waveform change is made to the dispersion. The degradation caused by the dispersion is improved by performing the dispersion compensation in each of the in-line amplifiers and on the receiving side. That is, the waveform is improved (the pulse width is narrowed), and input to the receiver.

One advantage of this compensation method is that the dispersion compensation can be made effective on the transmitting side. This is required for narrowing the pulse width of a waveform to be transmitted. By narrowing the pulse width and transmitting the signal having a narrowed pulse width to a transmission path, the amount of inter-symbol interference on one side of a logical value "0" is reduced. As a result, an improved transmission characteristic can be obtained. That is, the optimization of the narrowing of the waveform becomes vital, and the determination of the amounts of transmission chirping and dispersion compensation on a transmitting side depends on how to optimize the pulse width of the waveform.

Another advantage of this method is that the tolerance of the amount of dispersion compensation, which secures a transmission characteristic, can be increased. Since the pre-chirping of a transmitter is the red chirping, the pulse width of a waveform is widened at the time of propagation along an optical fiber of + dispersion. In the meantime, because the influence of the non-linear effect of an optical fiber is equivalent to the characteristic of the blue chirping, the pulse width is narrowed. That is, the influence of the non-linear effect is cancelled out by the pre-chirping of the transmitter. As a result, a slight waveform change is made to the dispersion. Accordingly, the range of the transmission distance which can satisfy a required transmission characteristic is widened for the amount of dispersion compensation. This leads to a reduction in the number of menus of a dispersion-compensator. That is, the most important point of this method is to how to set the α parameter.

In the system shown in Fig. 2, a transmission pulse is narrowed by combining the characteristics of the chirping parameter and the dispersion-compensator on the transmitting side, and is output to the transmission path. Furthermore, the characteristic of the chirping of the transmitter and transmission paths are cancelled

out by combining the characteristic of the chirping which occurs due to the influence of the non-linear effect on the transmission path and the characteristic of the transmission path. On the receiving side, the waveform, degraded due to the dispersion, is compensated (narrowing of the pulse width) by combining the characteristics of the chirping parameter and the dispersion-compensator.

Figs.3A and 3B are schematic diagrams showing the dependency of the range of a 1R transmittable distance corresponding to the change of an α parameter.

These schematic diagrams show the result of obtaining the range of the 1R transmittable distance range which can satisfy a required transmission characteristic for each α parameter under the predetermined conditions, such as the amount of dispersion compensation and the number of periods. As shown in Fig.3A, three repeaters 23, 24 and 25 are arranged between a transmitter 21 and a receiver 22. These repeaters are connected by the transmission paths 26, 27, 28 and 29. Fig.3B shows the result of obtaining for each α parameter the range in which a required transmission characteristic can be obtained, when the amount of dispersion compensation of each of the transmitter 21, receiver 22 and the repeaters 23, 24 and 25 is set to a constant value, and the 1R transmission interval is assumed to be a parameter.

As shown in Fig.3B, the range of the 1R transmission distance can be widely secured if the value of the α parameter is positive. Actually, the 1R transmission distance is short when the value of the α parameter is close to "0". To cancel out the non-linear effect occurring on a transmission path by making an optical output stronger, it is effective if the α parameter is set to a positive value. Accordingly, the α parameter adopts the positive value. Furthermore, it is estimated from the result of Fig.3B that the value of the α parameter in the neighborhood of "+1" is best. However, since this figure assumes that the transmission output is +14dBm, the result is obtained based on this assumption. If the transmission output is changed, the optimum value of the α parameter is considered to shift.

The transmission output in an in-line amplifier system is currently assumed to be of the order of +5 to +17dBm. Therefore, the change of the order of -9 to +3dB for +14dBm is considered. The amount of a shift of frequency at a light source is proportional to the α parameter, while the amount of a shift of frequency due to the non-linear effect of a transmission path fiber is proportional to a transmission output when the transmission distance is fixed. Therefore, the optimum value of the α parameter is considered to vary in proportion to the amount of change in the transmission output according to the present invention, where both amounts are mutually compensated.

Consequently, the optimum value of the α parameter is expected to change -9 to +3dB for +1, that is, in the range from 0.125 to 2. The lower limit, however, is replaced with "0" which is the lowest extreme in consideration of the case in which optical amplifiers are not used, and the transmission output level is low. Finally, the range from 0 to 2 is considered to be an effective range for the α parameter.

Accordingly, the range of the 1R transmittable distance can be widely secured in the range where the value of the α parameter is positive. This allows a reduction of the number of menus of a dispersion-compensator. Accordingly, it is effective that the α parameter is set within the positive range.

If the improvements on the conventional method are summarized according to the above description, the following points can be cited:-

1) The tolerance of the amount of dispersion compensation, which can secure a transmission characteristic, increases.
2) The number of menus can be reduced when menus of a dispersion-compensator are set according to a transmission distance as a product, as a result of 1).

Figs.4A and 4B exemplify a menu setting at the time of propagation along a single mode fiber.

As shown in Fig.4A, three repeaters are set, and the menu is set so that the dispersion compensation can be made in the 1R interval range from 0 to 80km. A dispersion-compensator is arranged in each of the transmitter 21, receiver 22, and the repeaters 23, 24 and 25. The amount of dispersion compensation on the transmitting side is assumed to be -600ps/nm, and menu of the amount of dispersion compensation within in-line amplifiers/on a receiving side is reviewed.

Fig.4B shows the result of the review of the menu within the in-line amplifiers/on the receiving side.

The shaded portion in Fig.4B represents an allowable 1R interval of each amount of dispersion compensation. As shown in Fig.4B, the range from 0 to approximately 22km can be secured as a 1R transmission distance between in-line amplifiers, or between an in-line amplifier and a receiver, if the amount of dispersion compensation is 0ps/nm. To secure the range of the 1R transmission distance exceeding approximately 22km, it is sufficient that the amount of dispersion compensation within an in-line amplifier or on a receiving side is set to -300ps/nm. This process allows the 1R transmission distance from approximately 22 to 38km to be covered. Similarly, the dispersion of a transmission path between in-line amplifiers or between an in-line amplifier and a receiver can be compensated by setting the amounts of dispersion compensation to -600ps/nm for the range from approximately 38 to 58km, -900ps/nm for the range from approximately 58 to 78km, and -1200ps/nm for the range from approximately 78 to 80km.

As described above, an optical transmission system which uses in-line amplifiers and prevents the

waveform of an optical signal from degrading can be implemented by preparing five menus 0, -300, -600, -900 and -1200ps/nm as dispersion compensation menus, when the 1R interval is set at a range from 0 to 80km.

In an actual system, the 1R interval may differ for each interval. Even in such a case, the dispersion compensation can be made in order to obtain a required transmission characteristic with this method. The present invention is characterized in that the amount of dispersion compensation is set depending on a distance prior to a repeater.

Fig.5 shows the method for compensating dispersion and the degradation of a waveform on a receiving side when a 1R interval differs for each interval at the time of propagation along a single mode fiber.

The amount of dispersion compensation on a transmitting side is assumed to be -600ps/nm, and two methods for compensating dispersion within in-line amplifiers/on a receiving side are presented. The upper compensation condition (1) is intended for a 3R transmission distance, and the amount of dispersion compensation within an in-line amplifier and on a receiving side is set to an identical value. The lower compensation condition (2) is intended for the 1R transmission distance, and the amounts of dispersion compensation within an in-line amplifier and on a receiving side are respectively set. Fig.5 shows the equalized waveforms of the O/E.

Under the upper compensation condition (1) shown in Fig.5, both amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to -600ps/nm. Judging from the eye patterns obtained for the various patterns of the 1R interval, an eye opening of a certain degree is obtained if the 1R interval is set to 80 and 10km in turn. However, since almost no opening is obtained in the other cases, it is nearly impossible to properly read the logical values "1" and "0".

In the meantime, under the lower compensation condition (2), the amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to 0ps/nm if the 1R interval is 10km, and to -1200ps/nm if the 1R interval is 80km, so that the amounts are suitable for the preceding 1R interval. This method for setting menus is performed according to the graph shown in Fig.4B.

By suitably setting the amount of dispersion compensation so as to correspond to a preceding 1R interval, as described above, an eye opening which is wide enough can be obtained as indicated by the lower eye pattern shown in Fig.5. As a result, the logical values "1" and "0" can be accurately obtained.

Especially, when a short distance of 10km first exists, the transmission characteristic significantly differs depending on the compensation methods. In this case, a better waveform can be obtained under the compensation condition (2) rather than the condition (1). That is, the method for determining the amount of dispersion compensation according to the distance prior to a repeater is effective.

Fig.6 is a schematic diagram showing the number of 1Rs, which satisfies a transmission characteristic required for the amount of dispersion compensation on a transmitting side, for each α parameter.

Fig.6 assumes that the 1R transmission distance is set to 80km, and both amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to -1000ps/nm. Here, the number of 1Rs is the number of relays using linear repeaters.

It can be seen from Fig.6 that if the α parameter is negative, a required transmission characteristic can be satisfied for up to only two 1Rs. However, setting the α parameter positive, this phenomenon can be improved. Especially, if the α parameter is +1, the required transmission characteristic can be obtained for widest range, and the maximum amount of dispersion compensation on the transmitting side will be -1200ps/nm.

To obtain the required transmission characteristic means that a waveform of a light pulse signal changes up to 10% in the amplitude direction and up to 30% in the phase direction in comparison with the case in which no influence is given.

That is, it is shown from Fig.6 that a longer transmission distance can be secured by which a required transmission characteristic can be obtained when the α parameter is positive rather than negative. Especially, the longest transmission distance can be secured if the value of the α parameter is +1.

Note that, however, the value of the α parameter which can obtain the longest transmission distance may vary when a transmission output of an optical signal is changed. This is because the optimum value of the α parameter depends on the optical transmission output. At least, it can be said from this figure that it is better to set the α parameter to a positive value rather than to a negative value.

Fig.7 is a schematic diagram showing the relationship of a 1R interval to an amount of 1R residual dispersion.

This figure assumes that the number of 1Rs (the number of repeaters) is 3, the value of the α parameter is +1, an optical transmission power is +13 to +14dBm, the amount of dispersion compensation on a transmitting side is -600ps/nm, and the amounts of dispersion compensation within an in-line amplifier and on a receiving side are 0 to -1200ps/nm. The amount of 1R residual dispersion (the amount of residual dispersion at 1R intervals) is examined in the range of the 1R interval from 0 to 80km based on this assumption.

It can be seen from Fig.7 that a required transmission characteristic can be obtained by setting the amount of 1R residual dispersion to approximately 100 to 400ps/nm even if the 1R interval varies. The number of repeaters is 3 in this figure. However, if the number of repeaters is set at 2, a repeater interval is expected to

be extended up to 120km. Therefore, the maximum amount of dispersion compensation on the receiving side is obtained based on the assumption that the repeater interval is 120km. Assuming that the amount of fiber chromatic dispersion is 20ps/nm/km in this case, the amount of dispersion of the 1R interval will be 2400ps/nm. The maximum amount of dispersion compensation on the receiving side can be obtained as being -2300ps/nm by subtracting the minimum amount of 1R residual dispersion 100ps/nm from the above described amount.

The above described embodiment assumes a transmission speed which is too great to ignore the nonlinear effect that an optical signal undergoes on a transmission path. For example, the speed is 10Gbps.

According to any of the above described embodiments, a dispersion compensator prepared by a receiving side can be combined with a module having the same amount of dispersion compensation. For example, the amounts of dispersion compensation within an in-line amplifier and on a receiving side are a multiple of -300ps/nm such as 0, -300, -600, -900 and -1200ps/nm in the menu setting shown in Fig.4B. By the above menu, such amounts of dispersion compensation can cover the 1R interval of up to 80km. Accordingly, a module having the amount of dispersion compensation -300ps/nm may be used as a unit of menu, and combined so as to obtain a required amount of dispersion compensation.

That is, the amount of dispersion compensation must be basically changed according to a transmission distance (the amount of dispersion which occurs on a transmission path). There is a conventional method for measuring the amount of dispersion on each transmission path, and setting the amount of dispersion compensation in order to keep the amount of residual dispersion constant. With this method, however, innumerable types of dispersion-compensators, which must be custom-built, are required. As a result, an economic problem occurs when this method is put into practice. There is another conventional method for appropriately dividing a transmission distance, determining the amount of dispersion compensation for each divided interval, and setting menus of a dispersion-compensator. If the number of menus is large, however, the number of types of peripheral parts increases. That is, it is not economical.

According to the present invention, a minimum unit of the amount of dispersion compensation (for example, -300ps/nm) is set, and only one type is basically used as the unit of dispersion compensation. Modules respectively having the amount of dispersion compensation of the minimum unit are connected in order to realize a required amount of dispersion compensation according to a transmission distance. If such a dispersion-compensator is used, it is not necessary to change the dispersion-compensator itself, even if a transmission distance is changed due to a moving of equipment. It is sufficient only to add or remove a module (or modules). Additionally, since the number of types of preparatory parts of modules is only 1, it is very economical.

With the above described method, however, there is a probability that the transmission characteristic cannot be secured depending on a use condition such as non-uniformity of fibers, a change of an output power, etc. It is effective that a dispersion-compensating module for correction (such as a module having the amount of dispersion compensation -100ps/nm) is prepared in order to cope with the case in which the above described case should happen, and is added in order to make a subtle adjustment.

There is also the case in which the input/output level of a dispersion-compensator is made constant, and the loss of the dispersion-compensator must be within a predetermined range regardless of the amount of dispersion compensation. For example, the restriction imposed by the input levels of an O/E, a post-amplifier, etc. In such a case, the loss of the dispersion-compensator will be included within a required range by additionally using an optical attenuator and causing a loss with an intentional shift of an optical axis at the time of a splice, even if the amount of dispersion compensation is changed. It prevents a succeeding device from being influenced.

As a method for connecting a module, a connection by a splice (fusion of fibers), a connection using a connector etc., can be cited. The module itself may be configured so that it can be attached/detached.

Figs.8A through 8D are schematic diagrams explaining modules of a dispersion-compensator. Figs.8A and 8B show variations of an arrangement of modules. Fig.8A shows a variation in which modules are arranged in series or side by side, while Fig.8B shows a variation in which modules are stacked.

Figs.8C and 8D show a connection method in the above cases. Fig.8C shows a method for arranging one of the input and output terminals on one of the opposing sides, and arranging the other of the two terminals on the other of the two sides. Fig.8D shows the structure in which both input and output terminals are arranged on one side. In this case, a module includes a switching circuit, which detects the insertion of a terminal when another module is connected and opens a closed potion, so that the modules become connected.

Figs.9A and 9B exemplify the structures of an optical switch for use in a module of a dispersion-compensator.

Fig.9A shows the implementation in which the insertion of a module is detected in the arrangement shown in Fig.8D. When switches 132 and 133 are closed, an optical path is established between A and C. Light is input to an output port 130, and output from an output port 131. In this implementation, light may be input to the output port 131, and output from the output port 130. Dispersion compensation is made in a portion "A" of the optical path. A portion "C" of the optical path

is a normal path which does not have a dispersion compensation capability.

When another module is connected, the output and input ports of that module are inserted into module insertion detector 135 and 136. The module connection detectors 135 and 136 detect that another module has been connected, and send a signal to a module connection detecting signal processing unit 137. The module connection detecting signal processing unit 137 sends a control signal to the switches 132 and 133 based on this signal. Again, based on this control signal, the switches 132 and 133 switch the optical path so that light travels through A and B.

The switches 132 and 133 may be of any type as long as they can switch an optical path upon receipt of an electric signal. A mechanical switch is available on the market.

Fig.9B exemplifies the specific structure of the module connection detector .

The module connection detector is arranged in an adaptor 139 attached to a connector 138 of the module. In Fig.9B, a projecting portion is arranged as a detector 141. When a connector 140, arranged at the output port of another module, is inserted into the adaptor 139, the projecting portion of the detector 141 moves, turns on a switch 142, arranged at a different location which is electrically connected, and generates a connection detection output. The module connection detecting signal processing unit 137 detects this output, and switches an optical path within the module.

A dispersion-compensating fiber can be used as the implementation of dispersion compensation. In addition, various components are available for the dispersion compensation.

Figs.10A through 10C are schematic diagrams showing the implementation of dispersion compensation other than a dispersion-compensating fiber.

Fig.10A shows a fiber-grating type dispersion-equalizer.

Assume that a grating (a cyclic change of a refractive index) 144 is provided to a fiber 143, and its cycle is changed by degrees. If light is input to the fiber 143, the light is reflected at points which differ depending on wavelength, and returns. Since the light, to which a different delay time is provided depending on the wavelength, returns, it is extracted using a circulator 145, and dispersion-equalized. If the direction of the input to the fiber grating is reversed, a dispersion characteristic of the opposite sign can be obtained.

Fig.10B shows a waveguide type dispersion-equalizer.

Assume that a waveguide 146 is formed using silicon dioxide (SiO_2)on an Si substrate, and a phase shifter 149 is arranged so that the phases of an upper waveguide 147 and a lower waveguide 148 differ from each other. For example, the component of an input optical signal on a long wavelength side propagates along the lower part, while the component on a short wavelength side propagates along the upper part by means of phase adjustment made by a phase shifter 149. A negative dispersion characteristic can be obtained by making the signal propagate along such a waveguide a number of times. Also a dispersion characteristic of the opposite sign can be obtained by adjusting a phase. For example, a thin film heater is used as the phase shifter 149.

Fig.10C shows a resonator type dispersion-equalizer.

A total reflecting mirror 151 and a translucent mirror 150 are opposed. If light is input from the translucent mirror 150, only a light having a certain wavelength according to the distance between both of the mirrors is multiplex-reflected in between, and resonated. Light which is multiplex-reflected a certain number of times proportional to a frequency, and has a frequency in the neighborhood of the resonant wavelength, returns. This light is extracted using a circulator, and a delay time which may differ depending on its frequency (wavelength) is provided and dispersion-equalized. A dispersion characteristic of an opposite direction can be obtained depending on the region to be used at a frequency which is either higher or lower than the resonant frequency.

The tolerance of the amount of dispersion compensation which can secure a required transmission characteristic to be secured can be improved by recognizing chirping provided to an optical signal on a transmitting side as red chirping whose α parameter is positive, arranging a dispersion-compensator in a receiver, adjusting the amount of dispersion compensation of a dispersion-compensator in order to compensate the dispersion of a preceding transmission path in a repeater, and arranging a dispersion-compensator also in a receiver. As a result, the number of menus can be reduced when menus of a dispersion-compensator are set according to a transmission distance.

Furthermore, an optical output can be made higher since the non-linear effect on a transmission path is cancelled by performing the red chirping on the transmitting side.

Claims

1. An optical transmission system which uses in-line amplifiers, and comprises a transmitter (1), repeaters (3, 5), a receiver (7) and transmission paths (2, 4, 6) connecting these components, wherein

   the transmitter (1) performs chirping whose α parameter is positive, for an optical signal; and the transmitter (1), the repeaters (3, 5) and the receiver (7) respectively include a dispersion-compensator (9, 11, 12, 14).

2. An optical transmission system which uses in-line amplifiers, and comprises a transmitter (1), repeat-

ers (3, 5), a receiver (7) and transmission paths (2, 4, 6) connecting these components, wherein

the repeaters (3, 5) and the receiver (7) respectively include a dispersion-compensator (9, 11, 12, 14) having an amount of dispersion compensation for compensating dispersion of a transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7).

3. The optical transmission system according to claim 1, wherein the α parameter is set in a range from "0" to "2".

4. The optical transmission system according to claim 1 or 2, wherein the transmitter (1) includes a dispersion-compensator (9) having a predetermined amount of dispersion compensation.

5. The optical transmission system according to claim 4, wherein the amount of dispersion compensation of the dispersion-compensators (9) included in the transmitter (1) is set to -1200ps/nm or less.

6. The optical transmission system according to claim 1 or 2, wherein the amount of dispersion compensation of the dispersion-compensators (11, 12, 14) respectively included in the repeaters (3, 5) or the receiver (7) is set to -2300ps/nm or less.

7. The optical transmission system according to claim 1, wherein

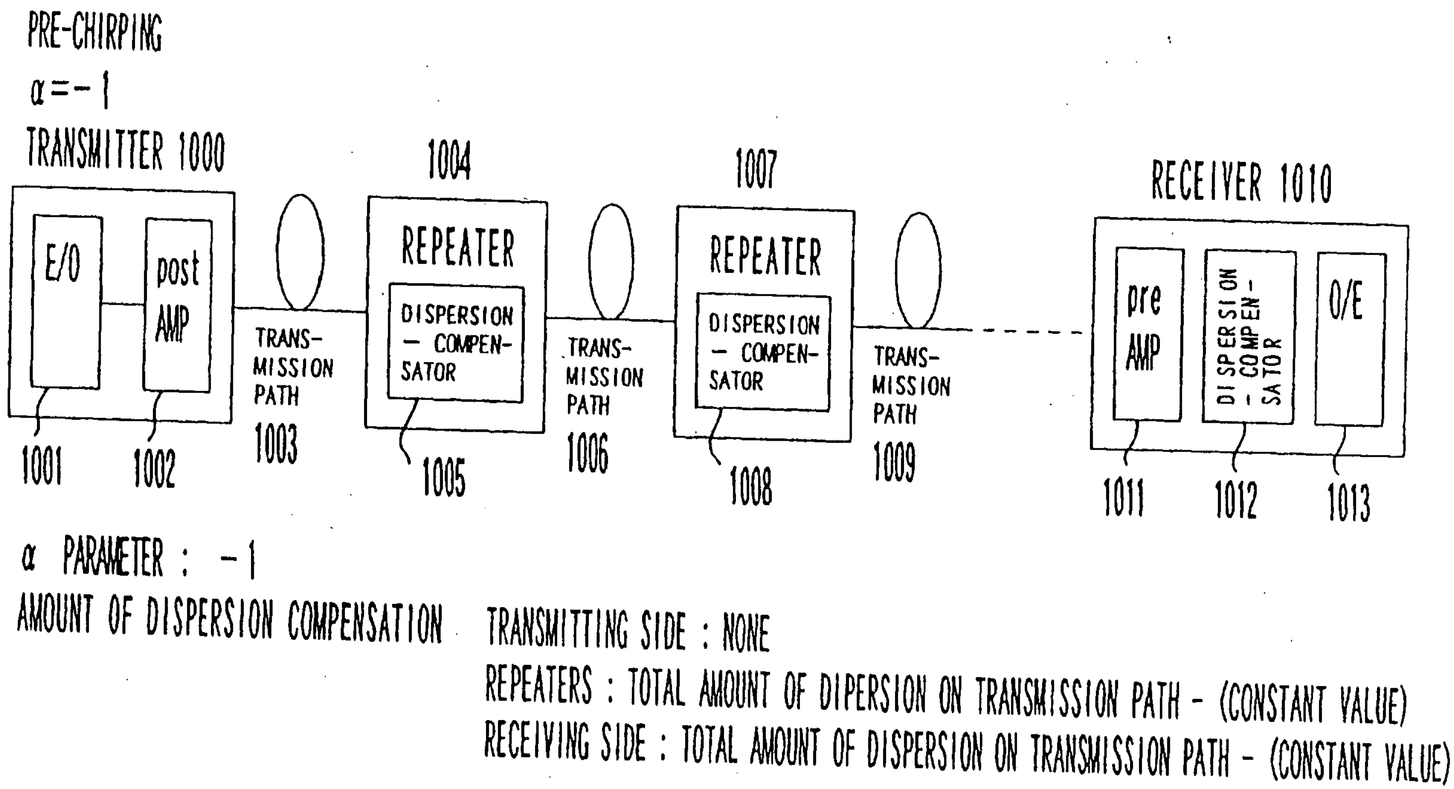
the value of the α parameter is set to approximately +1;
the amount of dispersion compensation of the dispersion-compensator (9) included in the transmitter (1) is set to approximately -600ps/nm;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to 0ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 0 to 22km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -300ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 22 to 38km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -600ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 38 to 58km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -900ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 58 to 78km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -1200ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 78 to 80km;
so that the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) and the receiver (7) is changed according to the length of a preceding transmission path (2, 4, 6).

8. The optical transmission system according to claim 1 or 2, wherein said dispersion-compensator (11, 12, 14) is implemented by using a dispersion-compensating fiber.

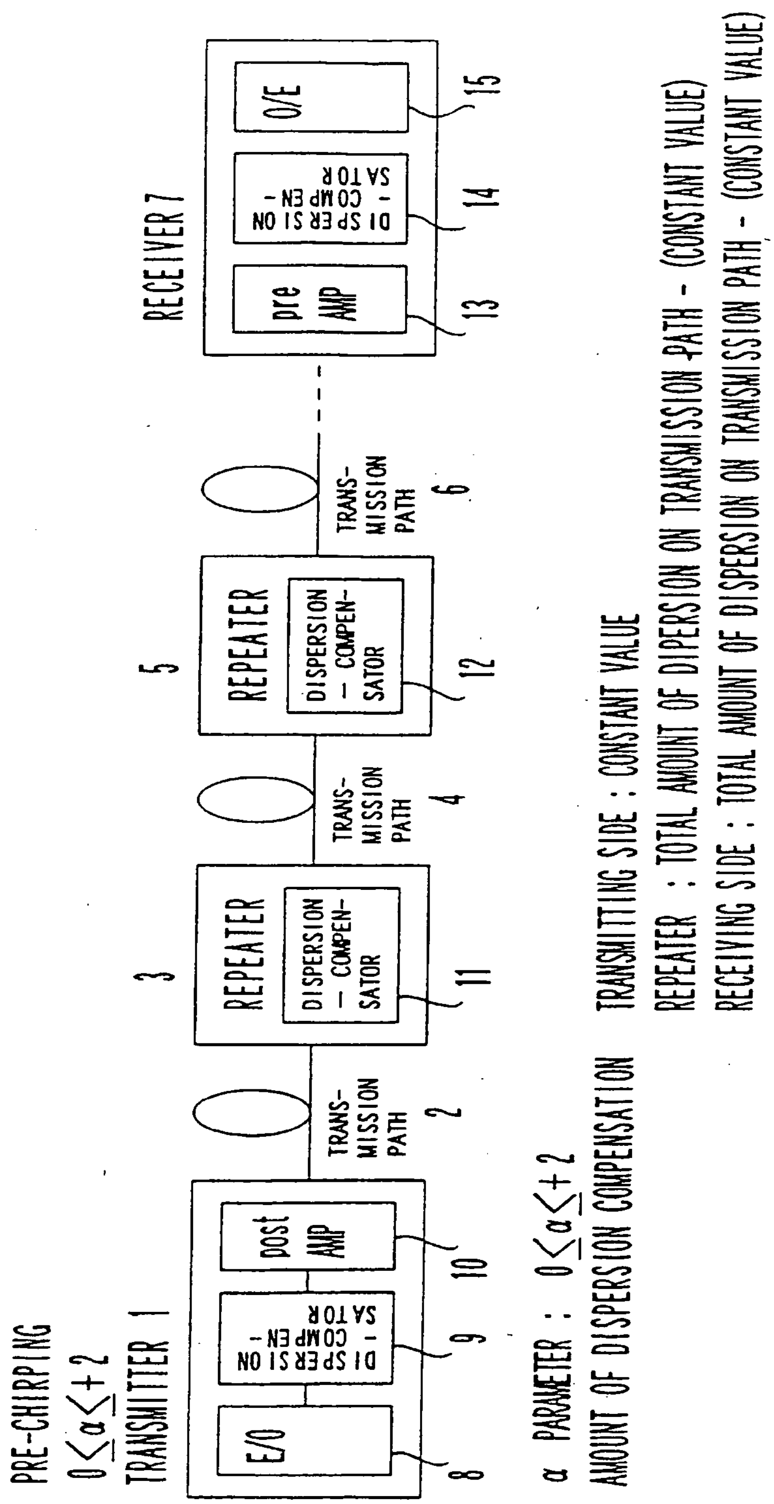
9. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a fiber grating.

10. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a waveguide type dispersion-equalizer.

11. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a resonator type dispersion-equalizer.



F I G. 1 PRIOR ART


PRE-CHIRPING
0≤α≤+2
TRANSMITTER 1
E/O
DISPERSION COMPEN-SATOR
post AMP
8
9
10
TRANS-MISSION PATH
2
3
REPEATER
DISPERSION — COMPEN-SATOR
11
TRANS-MISSION PATH
4
5
REPEATER
DISPERSION — COMPEN-SATOR
12
TRANS-MISSION PATH
6
RECEIVER 7
pre AMP
DISPERSION COMPEN-SATOR
O/E
13
14
15
α PARAMETER : 0≤α≤+2
AMOUNT OF DISPERSION COMPENSATION
TRANSMITTING SIDE : CONSTANT VALUE
REPEATER : TOTAL AMOUNT OF DIPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)
RECEIVING SIDE : TOTAL AMOUNT OF DISPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)

F I G. 2

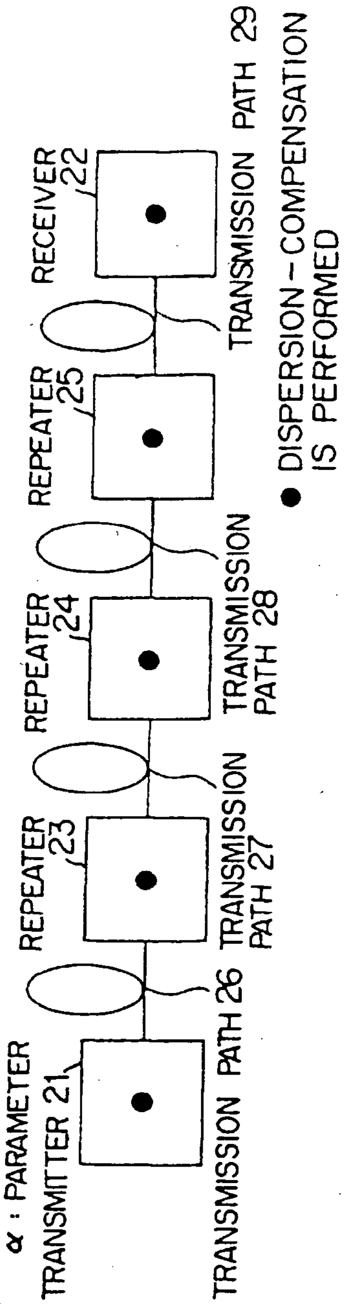

α : PARAMETER
TRANSMITTER 21
TRANSMISSION PATH 26
REPEATER 23
TRANSMISSION PATH 27
REPEATER 24
TRANSMISSION PATH 28
REPEATER 25
TRANSMISSION PATH 29
RECEIVER 22
● DISPERSION-COMPENSATION IS PERFORMED

FIG. 3A

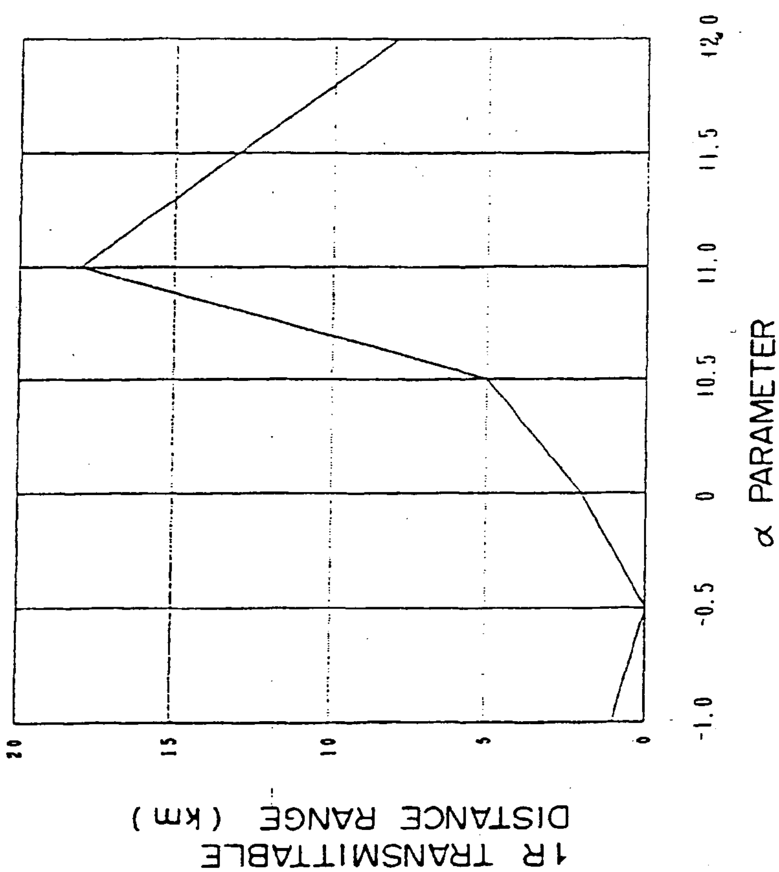

1R TRANSMITTABLE DISTANCE RANGE (km)
20
15
10
5
0
-1.0
-0.5
0
10.5
11.0
11.5
12.0
α PARAMETER

FIG. 3B

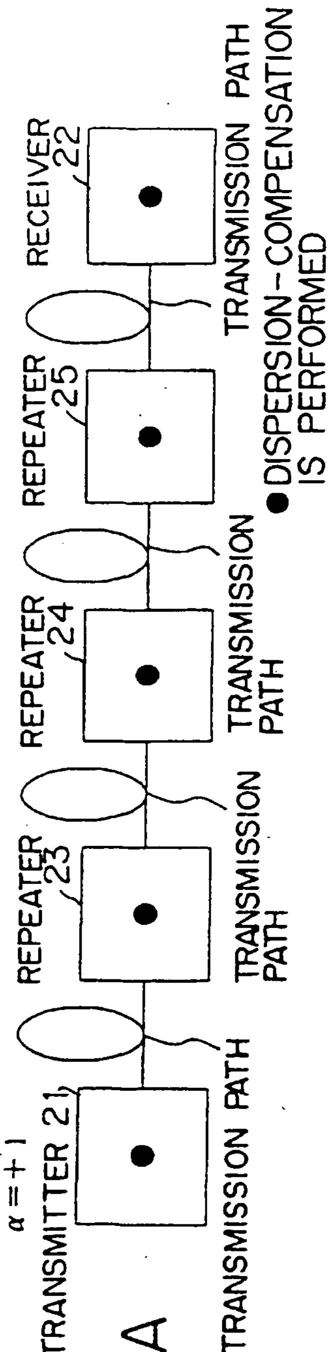

α = + 1
TRANSMITTER 21
TRANSMISSION PATH
REPEATER 23
TRANSMISSION PATH
REPEATER 24
TRANSMISSION PATH
REPEATER 25
TRANSMISSION PATH
RECEIVER 22
TRANSMISSION PATH
●DISPERSION-COMPENSATION IS PERFORMED

FIG. 4A

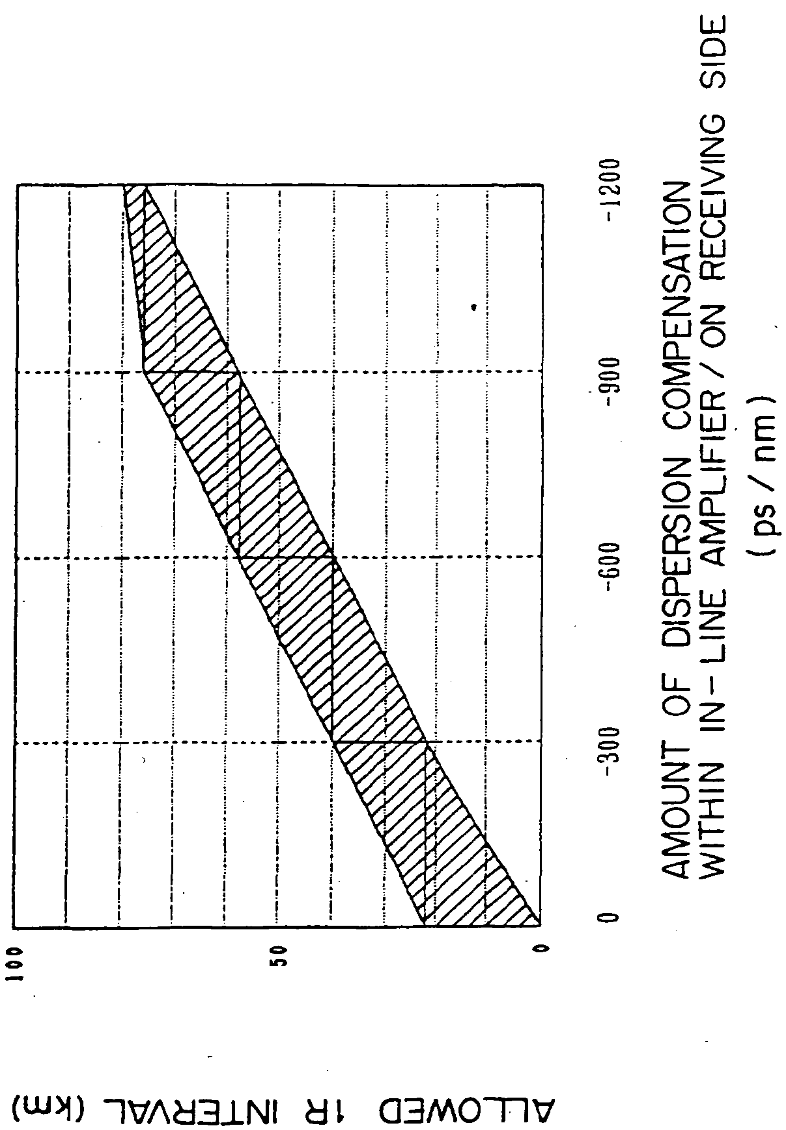

ALLOWED 1R INTERVAL (km)
100
50
0
0
-300
-600
-900
-1200
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER / ON RECEIVING SIDE
(ps / nm)

FIG. 4B

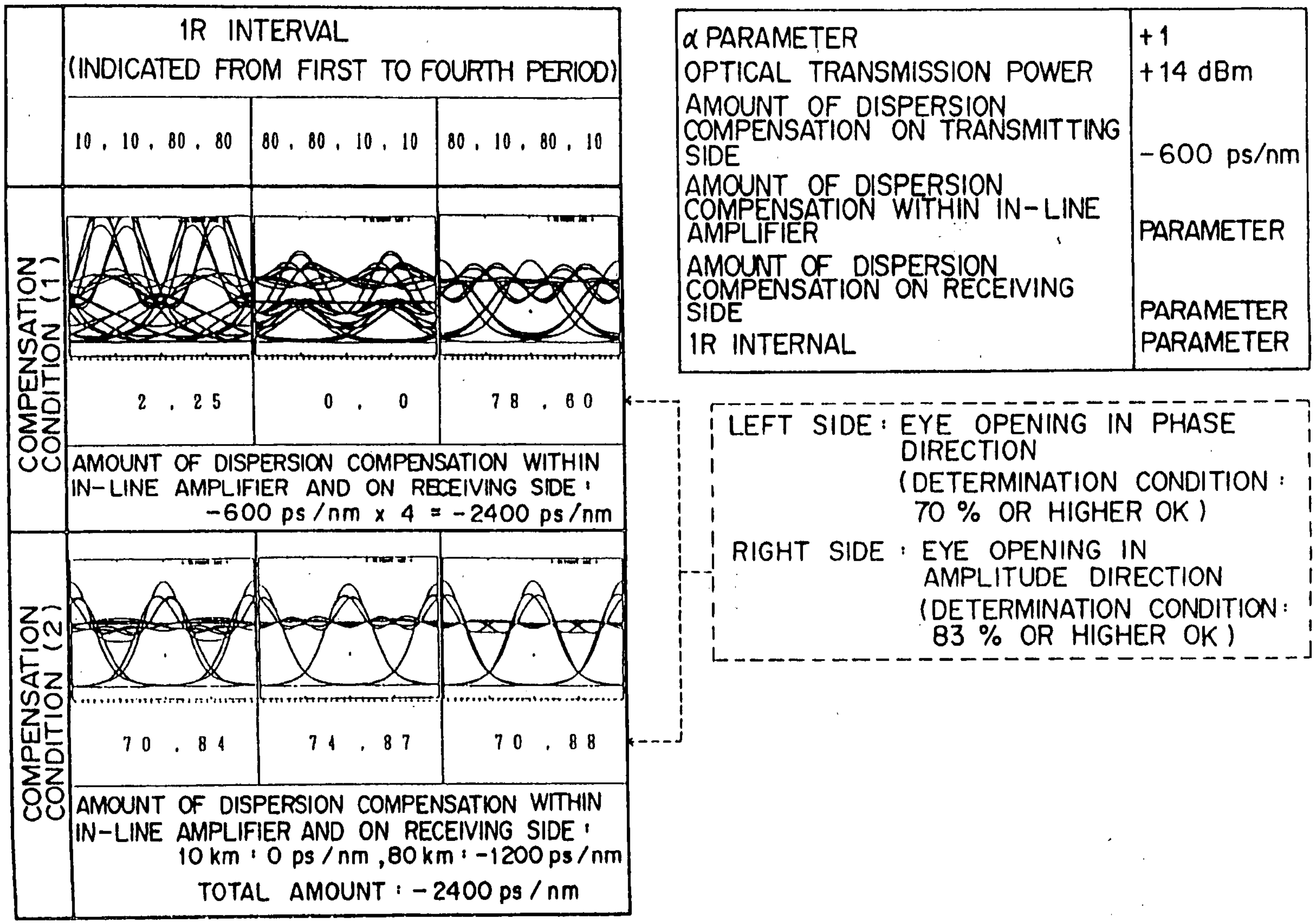
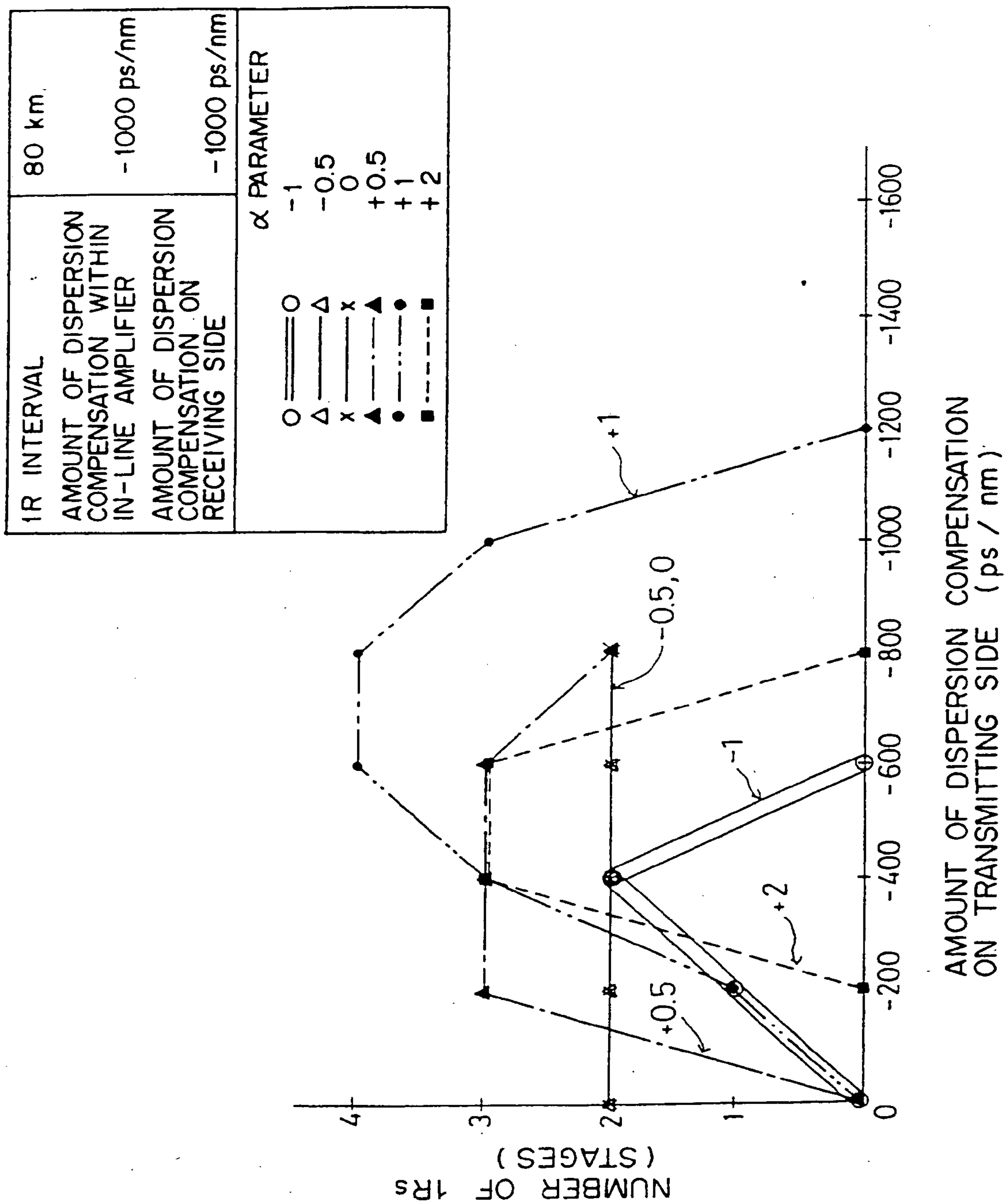

1R INTERVAL
(INDICATED FROM FIRST TO FOURTH PERIOD)
10, 10, 80, 80
80, 80, 10, 10
80, 10, 80, 10
COMPENSATION CONDITION (1)
2 , 25
0 , 0
78 , 60
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER AND ON RECEIVING SIDE : -600 ps/nm x 4 = -2400 ps/nm
COMPENSATION CONDITION (2)
70 , 84
74 , 87
70 , 88
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER AND ON RECEIVING SIDE : 10 km : 0 ps/nm , 80 km : -1200 ps/nm
TOTAL AMOUNT : -2400 ps/nm
α PARAMETER
+1
OPTICAL TRANSMISSION POWER
+14 dBm
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE
-600 ps/nm
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER
PARAMETER
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE
PARAMETER
1R INTERNAL
PARAMETER
LEFT SIDE : EYE OPENING IN PHASE DIRECTION
(DETERMINATION CONDITION : 70 % OR HIGHER OK)
RIGHT SIDE : EYE OPENING IN AMPLITUDE DIRECTION
(DETERMINATION CONDITION : 83 % OR HIGHER OK)

FIG. 5



1R INTERVAL
80 km
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER
-1000 ps/nm
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE
-1000 ps/nm
α PARAMETER
-1
-0.5
0
+0.5
+1
+2
NUMBER OF 1Rs (STAGES)
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE (ps / nm)
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
1
2
3
4
+1
-0.5,0
-1
+2
+0.5

FIG. 6

NUMBER OF 1RS	3
1R INTERVAL	0 ~ 80 km
α PARAMETER	+1
OPTICAL TRANSMISSION POWER	+13~14 dBm
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE	-600 ps / nm
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER	0 ~ -1200 ps / nm
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE	0 ~ -1200 ps / nm

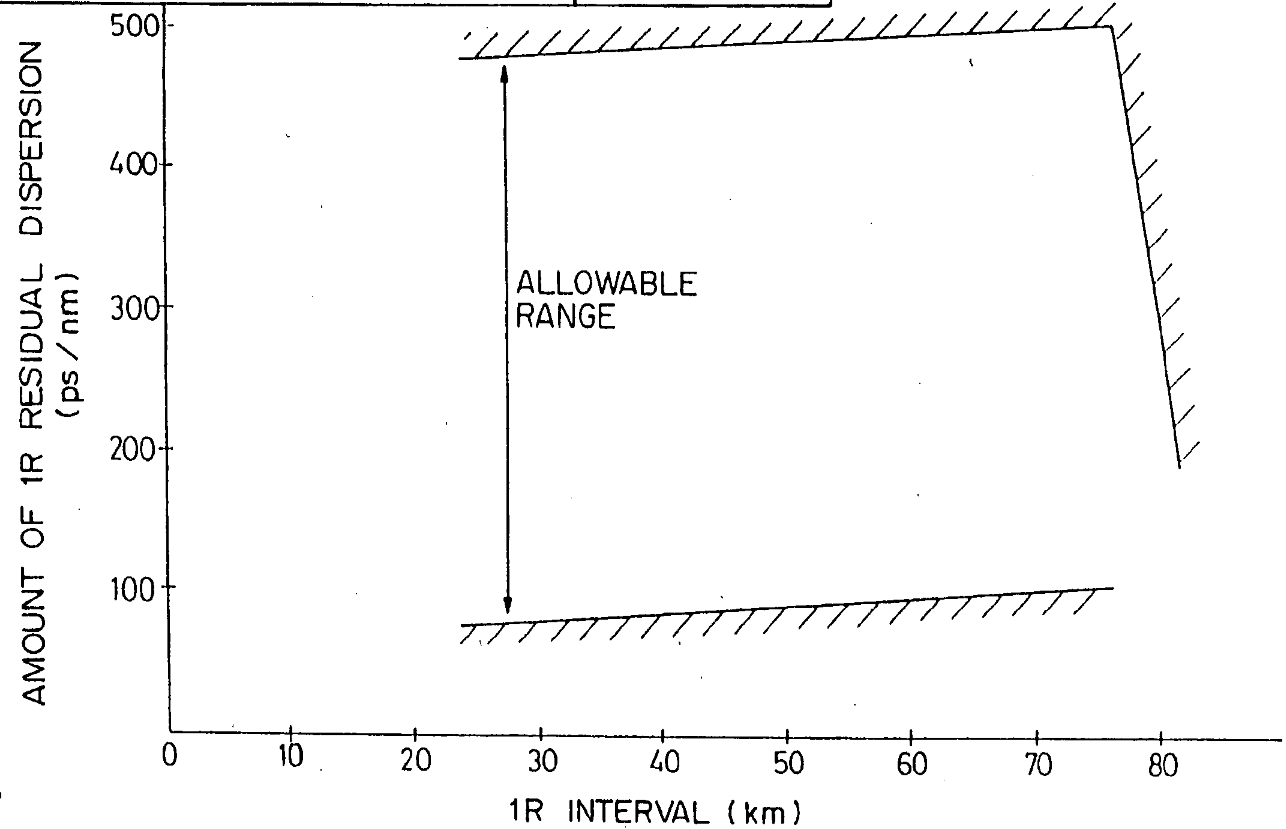


FIG. 7

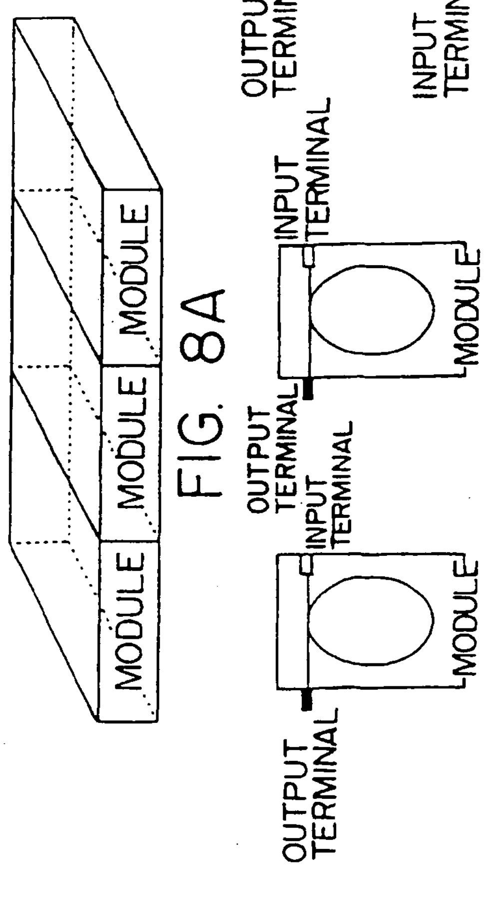


FIG. 8A

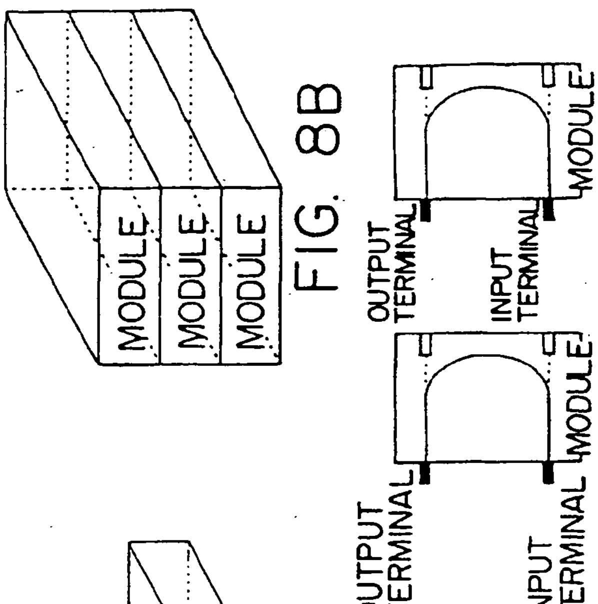


FIG. 8B

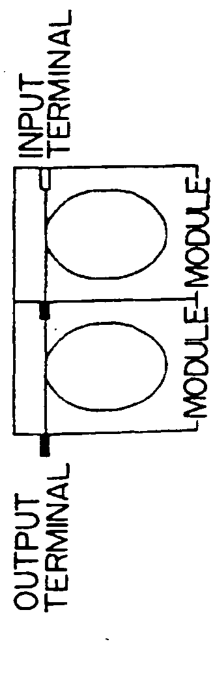


FIG. 8C

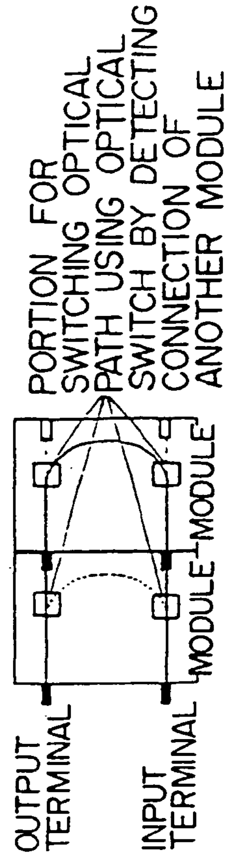


FIG. 8D

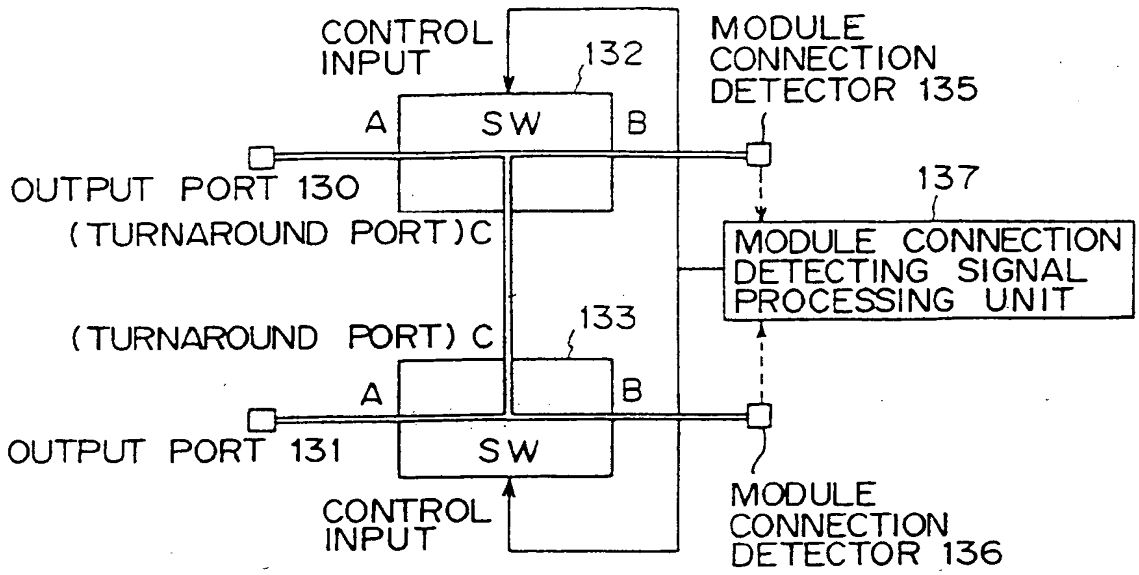

CONTROL
INPUT
132
SW
A
B
MODULE
CONNECTION
DETECTOR 135
OUTPUT PORT 130
(TURNAROUND PORT)C
137
MODULE CONNECTION
DETECTING SIGNAL
PROCESSING UNIT
(TURNAROUND PORT) C
133
A
B
OUTPUT PORT 131
SW
CONTROL
INPUT
MODULE
CONNECTION
DETECTOR 136

FIG. 9A

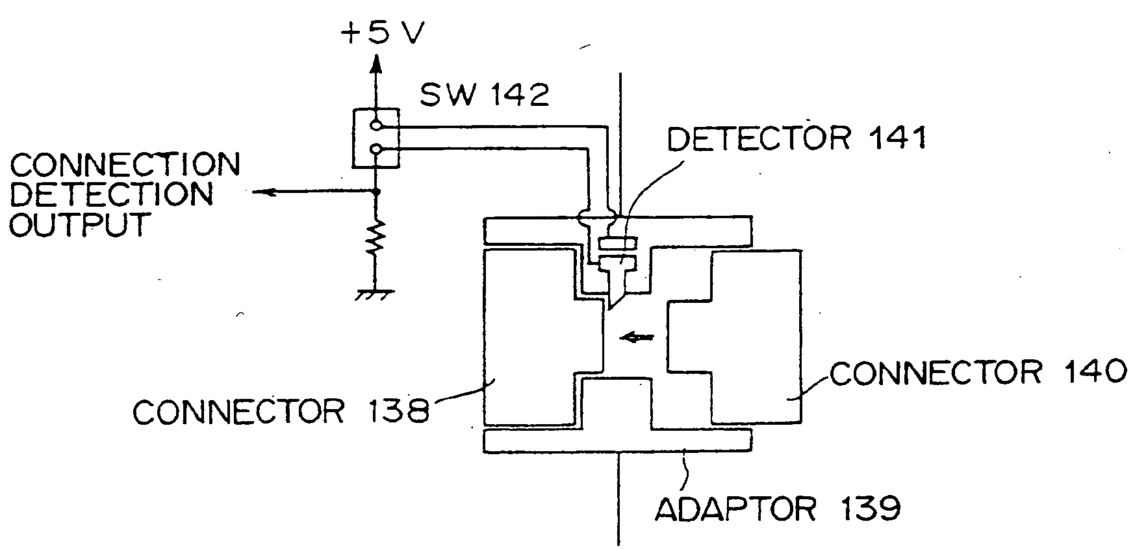

+5 V
SW 142
DETECTOR 141
CONNECTION
DETECTION
OUTPUT
CONNECTOR 140
CONNECTOR 138
ADAPTOR 139

FIG. 9B

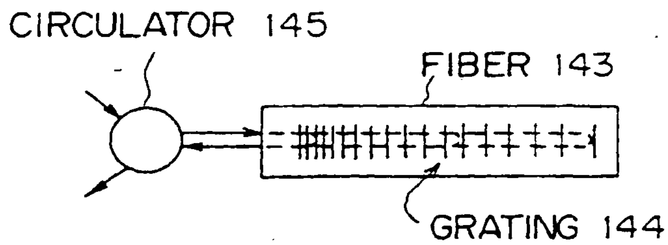


FIG. 10A

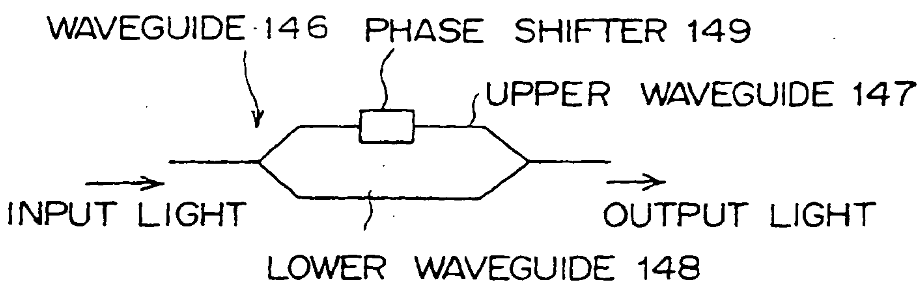


FIG. 10B

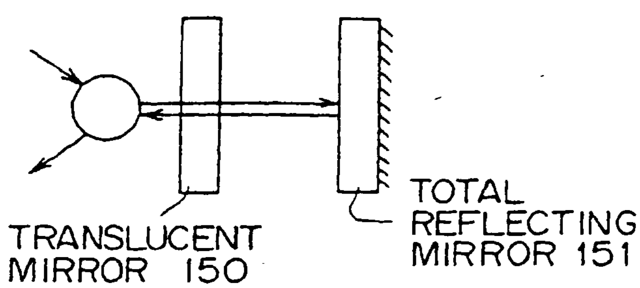


FIG. 10C

(19) Europäisches Patentamt
European Patent Office
Office eur p´ n des brevets

(11) EP 0 862 285 A3

(12) EUROPEAN PATENT APPLICATION

(88) Date of publication A3:
31.10.2001 Bulletin 2001/44

(51) Int Cl.7: H04B 10/18

(43) Date of publication A2:
02.09.1998 Bulletin 1998/36

(21) Application number: 97116632.7

(22) Date of filing: 24.09.1997

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV RO SI

(30) Priority: 27.02.1997 JP 4440797

(71) Applicant: FUJITSU LIMITED
Kawasaki-shi, Kanagawa 211-8588 (JP)

(72) Inventors:
- Miyauchi, Akira
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Yamane, Kazuo
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Kawasaki, Yumiko
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- Okano, Satoru, c/o Fujitsu H. D. Techn. Ltd.
  Sapporo-shi, Hokkaido 060 (JP)

(74) Representative:
von Fischern, Bernhard, Dipl.-Ing. et al
Hoffmann - Eitle,
Patent- und Rechtsanwälte,
Arabellastrasse 4
81925 München (DE)

(54) Optical transmission system using in-line amplifiers

(57) In a system connecting a transmitter and a receiver using transmission paths and repeaters (in-line amplifiers), red chirping whose α parameter is positive is performed for an optical signal on a transmitting side. Each of the repeaters includes a dispersion-compensator for compensating the amount of dispersion on a preceding transmission path. The amount of dispersion compensation of the dispersion-compensator included in the transmitter is made constant. The dispersion-compensator included in the receiver is arranged in order to compensate the amount of dispersion on a preceding transmission path. A spread of a pulse width on a transmission path can be efficiently compensated by using the compensation capability of the dispersion-compensators and the red chirping on the transmitting side.

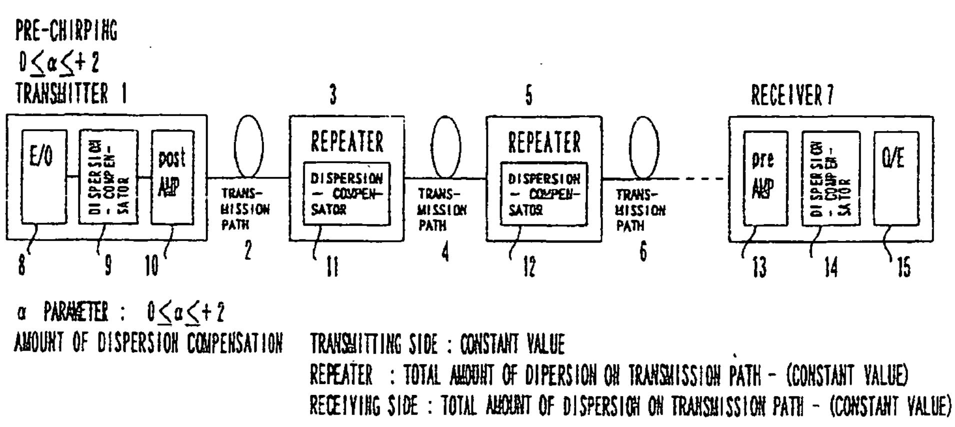


FIG. 2

EP 0 862 285 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 11 6632

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	EP 0 700 178 A (FUJITSU LTD) 6 March 1996 (1996-03-06) * page 11, line 18 - line 33 * * page 12, line 47 - line 53 * * page 19, line 7 - line 9 * * figures 14,21,43,49 *	1,2,4, 8-11 3	H04B10/18
Y	ISHIKAWA G ET AL: "10-GB/S REPEATERLESS TRANSMISSION USING STANDARD SINGLE-MODE FIBER WITH PRE-CHIRPING AND DISPERSION COMPENSATION TECHNIQUES" IEICE TRANSACTIONS ON ELECTRONICS, INSTITUTE OF ELECTRONICS INFORMATION AND COMM. ENG. TOKYO, JP, vol. E78-C, no. 1, 1995, pages 43-49, XP000495082 ISSN: 0916-8524 * page 43, left-hand column, line 38 - right-hand column, line 4 * * figure 2C *	3	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	JOPSON B ET AL: "DISPERSION COMPENSATION FOR OPTICAL FIBER SYSTEMS" IEEE COMMUNICATIONS MAGAZINE, IEEE SERVICE CENTER. PISCATAWAY, N.J, US, vol. 33, no. 6, 1 June 1995 (1995-06-01), pages 96-102, XP000545330 ISSN: 0163-6804 * the whole document *	1,8-11	H04B
A	FR 2 685 834 A (FRANCE TELECOM) 2 July 1993 (1993-07-02) * page 10, line 14 - line 30; figure 2 *	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	5 September 2001	Cochet, B

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 97 11 6632

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

05-09-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0700178 A	06-03-1996	JP 8321805 A	03-12-1996
		US 5991477 A	23-11-1999
		US 5870213 A	09-02-1999
		US 5717510 A	10-02-1998
		US 5909297 A	01-06-1999
		US 5815294 A	29-09-1998
		US 5754322 A	19-05-1998
		US 5896217 A	20-04-1999
		US 5760937 A	02-06-1998
FR 2685834 A	02-07-1993	GB 2263598 A,B	28-07-1993
		JP 5276121 A	22-10-1993
		US 5373382 A	13-12-1994

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

(between the pre-amplifier and the O/E). If the blue-chirping is performed in a fiber of + dispersion, an output pulse is compressed due to the characteristics of the fiber of + dispersion and the chirping. As a result, a transmission distance is made relatively longer. Especially, in a system which does not use optical amplifiers, an optical signal having the wavelength 1.5μm is more effective when it travels along a single mode fiber (1.3μm zero-dispersion). Accordingly, the dispersion compensation implemented by combining the pre-chirping and the succeeding compensation was considered to be also effective in a system using optical amplifiers. If the amount of dispersion compensation is set in order to keep a residual dispersion value (obtained by subtracting the amount of dispersion compensation from a total amount of dispersion of a transmission fiber) constant, a stable transmission characteristic can be obtained.

However, if output of the transmission power is increased by introducing optical amplifiers according to this method, the influence of the non-linear effect of an optical fiber remarkably appears. The influence of the non-linear effect is equivalent to the characteristic of the blue chirping. The pulse width of the transmission waveform is narrowed due to the influence of the pre-chirping of the transmitter and the non-linear effect of the optical fiber. As a result, the influence of the non-linear effect remarkably appears, and the waveform is significantly changed for the dispersion.

The problems posed by the method for performing the blue-chirping at the time of transmission are listed below.

1) Output of transmission power cannot be increased.
2) Dispersion-compensation on a transmitting side is ineffective.
3) The dispersion-compensation is performed in in-line amplifiers and on a receiving side due to the ineffectivity on the transmitting side in consideration with 2). Accordingly, the losses of dispersion-compensators become larger, and the tolerance of the losses becomes difficult as transmission distance is extended. Lowering the level of an optical input to the O/E leads to the degradation of reception sensitivity, and imposes a limitation. Furthermore, optical input power may sometimes have an upper limit depending on the dispersion-compensator to be used.
4) The tolerance of the amount of dispersion-compensation which can ensure the transmission characteristic is small.
5) The number of menus increases when menus of a dispersion-compensator according to a transmission distance are set as a product due to the small tolerance as a result of 4).

Summary of the Invention

The object of the present invention is to provide a technology which can compensate transmission degradation especially due to fiber dispersion, and ensure a transmission characteristic of a longer distance, in an optical in-line amplifier system.

The optical transmission system according to the present invention assumes the use of repeaters (in-line amplifiers). It comprises a transmitter, repeaters, a receiver and transmission paths for interconnecting these modules. The present invention is characterized in that the transmitter performs chirping whose α parameter is positive for an optical signal and each of the repeaters and the receiver include a dispersion-compensator having an amount of dispersion compensation for compensating dispersion of a transmission path preceding each of the repeaters and the receiver.

Since the non-linear effect that the optical signal receives on a transmission path corresponds to the blue chirping, this effect can be compensated by performing red chirping whose α parameter is positive on a transmitting side. This leads to the effect of preventing the waveform of the optical signal to be degraded.

Furthermore, the degradation of the optical signal can be prevented more effectively by setting the amount of dispersion compensation in order to compensate the dispersion of a preceding transmission path in each of the repeaters or the receiver.

With the above described configuration, an optical signal can be transmitted by performing the red chirping compensating the non-linear effect in order to prevent a waveform to be degraded even if an optical output is made higher on a transmitting side.

Additionally, since a menu of the amount of dispersion compensation in a repeater or a receiver can be constructed by a combination of unit modules, its implementation as a product is relatively easy.

Brief Description of the Drawings

Fig.1 is a schematic diagram showing a combination of a conventional pre-chirping and dispersion-compensators;

Fig.2 is a schematic diagram showing the basic configuration of an embodiment according to the present invention;

Figs.3A and 3B are schematic diagrams showing the dependency of a 1R transmittable distance range corresponding to a change of an α parameter;

Figs.4A and 4B exemplify a menu setting at the time of propagation along a single mode fiber;

Fig.5 is a schematic diagram showing a dispersion compensation method and the degradation of a waveform on a receiving side when a 1R interval varies depending on a period at the time of the propagation along a single mode fiber;

Fig.6 is a graph showing the number of 1Rs satisfying a transmission characteristic required for an amount of dispersion compensation on a transmitting side, which is obtained for each α parameter;

Fig.7 is a schematic diagram showing the relationship of a 1R interval to an amount of a 1R residual dispersion;

Figs.8A through 8D are schematic diagrams explaining unit modules of a dispersion-compensator;

Figs.9A and 9B exemplify the structure of an optical switch for use in a unit module of the dispersion-compensator; and

Figs.10A through 10C exemplify the structures for compensating dispersion other than a dispersion-compensating fiber.

Description of the Preferred Embodiments

Fig.2 is a schematic diagram showing the basic configuration of an optical transmission system according to an embodiment of the present invention.

In this figure, a transmitter 1 and a receiver 7 are connected by transmission paths 2, 4, 6,... and repeaters 3, 5,.... The transmitter 1 is composed of an E/O (Electric-to-optical signal converter) 8, a dispersion-compensator 9 and a post-amplifier 10. The E/O 8 is intended to convert an electric signal into an optical signal. The dispersion-compensator is intended to perform a predetermined amount of dispersion compensation on the side of the transmitter 1. The post-amplifier 10 is intended to amplify an optical output in order to allow the optical signal to be transmitted farther along a transmission path. In addition, red chirping whose α parameter ranges between 0 and +2 is performed on the side of the transmitter 1, according to the present invention. The amount of dispersion compensation of each of the dispersion-compensators 11 and 12 included in the repeaters 3 or 5 is adjusted in order to compensate the dispersion of the preceding transmission path (transmission path from the preceding repeater to the local repeater: the length of a transmission path between repeaters is referred to as a 1R transmission distance or a 1R interval). That is, the dispersion-compensator 11 possesses the amount of dispersion compensation necessary for compensating the dispersion of the transmission path 2, while the dispersion-compensator 12 possesses the amount of dispersion compensation necessary for compensating the dispersion of the transmission path 4. Also dispersion-compensators arranged in other repeaters, (not shown in this figure) are configured so that they possess the amount of dispersion compensation necessary for compensating the dispersion of a preceding transmission path. The receiver 7 is composed of a pre-amplifier 13, a dispersion-compensator 14, and an O/E (optical-to-electric signal converter) 15. The pre-amplifier 13 is intended to amplify a transmitted optical signal so that it can be detected with ease. The dispersion-compensator 14 is arranged in order to compensate the dispersion of the transmission path preceding the receiver 7. The O/E 15 is intended to convert an optical signal into an electric signal, and output the converted signal to a device for extracting data.

A transmitting side narrows the pulse width of the signal using the characteristics of transmission chirping and dispersion-compensation on the transmitting side, and outputs the signal having a narrow pulse width to a transmission path. The signal is influenced by the non-linear effect of a fiber (narrowing of the pulse width) and the dispersion of the fiber (widening of the pulse width). Since the, reciprocal effects of the influences are to be cancelled out by each other, a slight waveform change is made to the dispersion. The degradation caused by the dispersion is improved by performing the dispersion compensation in each of the in-line amplifiers and on the receiving side. That is, the waveform is improved (the pulse width is narrowed), and input to the receiver.

One advantage of this compensation method is that the dispersion compensation can be made effective on the transmitting side. This is required for narrowing the pulse width of a waveform to be transmitted. By narrowing the pulse width and transmitting the signal having a narrowed pulse width to a transmission path, the amount of inter-symbol interference on one side of a logical value "0" is reduced. As a result, an improved transmission characteristic can be obtained. That is, the optimization of the narrowing of the waveform becomes vital, and the determination of the amounts of transmission chirping and dispersion compensation on a transmitting side depends on how to optimize the pulse width of the waveform.

Another advantage of this method is that the tolerance of the amount of dispersion compensation, which secures a transmission characteristic, can be increased. Since the pre-chirping of a transmitter is the red chirping, the pulse width of a waveform is widened at the time of propagation along an optical fiber of + dispersion. In the meantime, because the influence of the non-linear effect of an optical fiber is equivalent to the characteristic of the blue chirping, the pulse width is narrowed. That is, the influence of the non-linear effect is cancelled out by the pre-chirping of the transmitter. As a result, a slight waveform change is made to the dispersion. Accordingly, the range of the transmission distance which can satisfy a required transmission characteristic is widened for the amount of dispersion compensation. This leads to a reduction in the number of menus of a dispersion-compensator. That is, the most important point of this method is to how to set the α parameter.

In the system shown in Fig. 2, a transmission pulse is narrowed by combining the characteristics of the chirping parameter and the dispersion-compensator on the transmitting side, and is output to the transmission path. Furthermore, the characteristic of the chirping of the transmitter and transmission paths are cancelled

out by combining the characteristic of the chirping which occurs due to the influence of the non-linear effect on the transmission path and the characteristic of the transmission path. On the receiving side, the waveform, degraded due to the dispersion, is compensated (narrowing of the pulse width) by combining the characteristics of the chirping parameter and the dispersion-compensator.

Figs.3A and 3B are schematic diagrams showing the dependency of the range of a 1R transmittable distance corresponding to the change of an α parameter.

These schematic diagrams show the result of obtaining the range of the 1R transmittable distance range which can satisfy a required transmission characteristic for each α parameter under the predetermined conditions, such as the amount of dispersion compensation and the number of periods. As shown in Fig.3A, three repeaters 23, 24 and 25 are arranged between a transmitter 21 and a receiver 22. These repeaters are connected by the transmission paths 26, 27, 28 and 29. Fig.3B shows the result of obtaining for each α parameter the range in which a required transmission characteristic can be obtained, when the amount of dispersion compensation of each of the transmitter 21, receiver 22 and the repeaters 23, 24 and 25 is set to a constant value, and the 1R transmission interval is assumed to be a parameter.

As shown in Fig.3B, the range of the 1R transmission distance can be widely secured if the value of the α parameter is positive. Actually, the 1R transmission distance is short when the value of the α parameter is close to "0". To cancel out the non-linear effect occurring on a transmission path by making an optical output stronger, it is effective if the α parameter is set to a positive value. Accordingly, the α parameter adopts the positive value. Furthermore, it is estimated from the result of Fig.3B that the value of the α parameter in the neighborhood of "+1" is best. However, since this figure assumes that the transmission output is +14dBm, the result is obtained based on this assumption. If the transmission output is changed, the optimum value of the α parameter is considered to shift.

The transmission output in an in-line amplifier system is currently assumed to be of the order of +5 to +17dBm. Therefore, the change of the order of -9 to +3dB for +14dBm is considered. The amount of a shift of frequency at a light source is proportional to the α parameter, while the amount of a shift of frequency due to the non-linear effect of a transmission path fiber is proportional to a transmission output when the transmission distance is fixed. Therefore, the optimum value of the α parameter is considered to vary in proportion to the amount of change in the transmission output according to the present invention, where both amounts are mutually compensated.

Consequently, the optimum value of the α parameter is expected to change -9 to +3dB for +1, that is, in the range from 0.125 to 2. The lower limit, however, is replaced with "0" which is the lowest extreme in consideration of the case in which optical amplifiers are not used, and the transmission output level is low. Finally, the range from 0 to 2 is considered to be an effective range for the α parameter.

Accordingly, the range of the 1R transmittable distance can be widely secured in the range where the value of the α parameter is positive. This allows a reduction of the number of menus of a dispersion-compensator. Accordingly, it is effective that the α parameter is set within the positive range.

If the improvements on the conventional method are summarized according to the above description, the following points can be cited:-

1) The tolerance of the amount of dispersion compensation, which can secure a transmission characteristic, increases.

2) The number of menus can be reduced when menus of a dispersion-compensator are set according to a transmission distance as a product, as a result of 1).

Figs.4A and 4B exemplify a menu setting at the time of propagation along a single mode fiber.

As shown in Fig.4A, three repeaters are set, and the menu is set so that the dispersion compensation can be made in the 1R interval range from 0 to 80km. A dispersion-compensator is arranged in each of the transmitter 21, receiver 22, and the repeaters 23, 24 and 25. The amount of dispersion compensation on the transmitting side is assumed to be -600ps/nm, and menu of the amount of dispersion compensation within in-line amplifiers/on a receiving side is reviewed.

Fig.4B shows the result of the review of the menu within the in-line amplifiers/on the receiving side.

The shaded portion in Fig.4B represents an allowable 1R interval of each amount of dispersion compensation. As shown in Fig.4B, the range from 0 to approximately 22km can be secured as a 1R transmission distance between in-line amplifiers, or between an in-line amplifier and a receiver, if the amount of dispersion compensation is 0ps/nm. To secure the range of the 1R transmission distance exceeding approximately 22km, it is sufficient that the amount of dispersion compensation within an in-line amplifier or on a receiving side is set to -300ps/nm. This process allows the 1R transmission distance from approximately 22 to 38km to be covered. Similarly, the dispersion of a transmission path between in-line amplifiers or between an in-line amplifier and a receiver can be compensated by setting the amounts of dispersion compensation to -600ps/nm for the range from approximately 38 to 58km, -900ps/nm for the range from approximately 58 to 78km, and -1200ps/nm for the range from approximately 78 to 80km.

As described above, an optical transmission system which uses in-line amplifiers and prevents the

waveform of an optical signal from degrading can be implemented by preparing five menus 0, -300, -600, -900 and -1200ps/nm as dispersion compensation menus, when the 1R interval is set at a range from 0 to 80km.

In an actual system, the 1R interval may differ for each interval. Even in such a case, the dispersion compensation can be made in order to obtain a required transmission characteristic with this method. The present invention is characterized in that the amount of dispersion compensation is set depending on a distance prior to a repeater.

Fig.5 shows the method for compensating dispersion and the degradation of a waveform on a receiving side when a 1R interval differs for each interval at the time of propagation along a single mode fiber.

The amount of dispersion compensation on a transmitting side is assumed to be -600ps/nm, and two methods for compensating dispersion within in-line amplifiers/on a receiving side are presented. The upper compensation condition (1) is intended for a 3R transmission distance, and the amount of dispersion compensation within an in-line amplifier and on a receiving side is set to an identical value. The lower compensation condition (2) is intended for the 1R transmission distance, and the amounts of dispersion compensation within an in-line amplifier and on a receiving side are respectively set. Fig.5 shows the equalized waveforms of the O/E.

Under the upper compensation condition (1) shown in Fig.5, both amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to -600ps/nm. Judging from the eye patterns obtained for the various patterns of the 1R interval, an eye opening of a certain degree is obtained if the 1R interval is set to 80 and 10km in turn. However, since almost no opening is obtained in the other cases, it is nearly impossible to properly read the logical values "1" and "0".

In the meantime, under the lower compensation condition (2), the amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to 0ps/nm if the 1R interval is 10km, and to -1200ps/nm if the 1R interval is 80km, so that the amounts are suitable for the preceding 1R interval. This method for setting menus is performed according to the graph shown in Fig.4B.

By suitably setting the amount of dispersion compensation so as to correspond to a preceding 1R interval, as described above, an eye opening which is wide enough can be obtained as indicated by the lower eye pattern shown in Fig.5. As a result, the logical values "1" and "0" can be accurately obtained.

Especially, when a short distance of 10km first exists, the transmission characteristic significantly differs depending on the compensation methods. In this case, a better waveform can be obtained under the compensation condition (2) rather than the condition (1). That is, the method for determining the amount of dispersion compensation according to the distance prior to a repeater is effective.

Fig.6 is a schematic diagram showing the number of 1Rs, which satisfies a transmission characteristic required for the amount of dispersion compensation on a transmitting side, for each α parameter.

Fig.6 assumes that the 1R transmission distance is set to 80km, and both amounts of dispersion compensation within an in-line amplifier and on a receiving side are set to -1000ps/nm. Here, the number of 1Rs is the number of relays using linear repeaters.

It can be seen from Fig.6 that if the α parameter is negative, a required transmission characteristic can be satisfied for up to only two 1Rs. However, setting the α parameter positive, this phenomenon can be improved. Especially, if the α parameter is +1, the required transmission characteristic can be obtained for widest range, and the maximum amount of dispersion compensation on the transmitting side will be -1200ps/nm.

To obtain the required transmission characteristic means that a waveform of a light pulse signal changes up to 10% in the amplitude direction and up to 30% in the phase direction in comparison with the case in which no influence is given.

That is, it is shown from Fig.6 that a longer transmission distance can be secured by which a required transmission characteristic can be obtained when the α parameter is positive rather than negative. Especially, the longest transmission distance can be secured if the value of the α parameter is +1.

Note that, however, the value of the α parameter which can obtain the longest transmission distance may vary when a transmission output of an optical signal is changed. This is because the optimum value of the α parameter depends on the optical transmission output. At least, it can be said from this figure that it is better to set the α parameter to a positive value rather than to a negative value.

Fig.7 is a schematic diagram showing the relationship of a 1R interval to an amount of 1R residual dispersion.

This figure assumes that the number of 1Rs (the number of repeaters) is 3, the value of the α parameter is +1, an optical transmission power is +13 to +14dBm, the amount of dispersion compensation on a transmitting side is -600ps/nm, and the amounts of dispersion compensation within an in-line amplifier and on a receiving side are 0 to -1200ps/nm. The amount of 1R residual dispersion (the amount of residual dispersion at 1R intervals) is examined in the range of the 1R interval from 0 to 80km based on this assumption.

It can be seen from Fig.7 that a required transmission characteristic can be obtained by setting the amount of 1R residual dispersion to approximately 100 to 400ps/nm even if the 1R interval varies. The number of repeaters is 3 in this figure. However, if the number of repeaters is set at 2, a repeater interval is expected to

be extended up to 120km. Therefore, the maximum amount of dispersion compensation on the receiving side is obtained based on the assumption that the repeater interval is 120km. Assuming that the amount of fiber chromatic dispersion is 20ps/nm/km in this case, the amount of dispersion of the 1R interval will be 2400ps/nm. The maximum amount of dispersion compensation on the receiving side can be obtained as being -2300ps/nm by subtracting the minimum amount of 1R residual dispersion 100ps/nm from the above described amount.

The above described embodiment assumes a transmission speed which is too great to ignore the nonlinear effect that an optical signal undergoes on a transmission path. For example, the speed is 10Gbps.

According to any of the above described embodiments, a dispersion compensator prepared by a receiving side can be combined with a module having the same amount of dispersion compensation. For example, the amounts of dispersion compensation within an in-line amplifier and on a receiving side are a multiple of -300ps/nm such as 0, -300, -600, -900 and -1200ps/nm in the menu setting shown in Fig.4B. By the above menu, such amounts of dispersion compensation can cover the 1R interval of up to 80km. Accordingly, a module having the amount of dispersion compensation -300ps/nm may be used as a unit of menu, and combined so as to obtain a required amount of dispersion compensation.

That is, the amount of dispersion compensation must be basically changed according to a transmission distance (the amount of dispersion which occurs on a transmission path). There is a conventional method for measuring the amount of dispersion on each transmission path, and setting the amount of dispersion compensation in order to keep the amount of residual dispersion constant. With this method, however, innumerable types of dispersion-compensators, which must be custom-built, are required. As a result, an economic problem occurs when this method is put into practice. There is another conventional method for appropriately dividing a transmission distance, determining the amount of dispersion compensation for each divided interval, and setting menus of a dispersion-compensator. If the number of menus is large, however, the number of types of peripheral parts increases. That is, it is not economical.

According to the present invention, a minimum unit of the amount of dispersion compensation (for example, -300ps/nm) is set, and only one type is basically used as the unit of dispersion compensation. Modules respectively having the amount of dispersion compensation of the minimum unit are connected in order to realize a required amount of dispersion compensation according to a transmission distance. If such a dispersion-compensator is used, it is not necessary to change the dispersion-compensator itself, even if a transmission distance is changed due to a moving of equipment. It is sufficient only to add or remove a module (or modules). Additionally, since the number of types of preparatory parts of modules is only 1, it is very economical.

With the above described method, however, there is a probability that the transmission characteristic cannot be secured depending on a use condition such as non-uniformity of fibers, a change of an output power, etc. It is effective that a dispersion-compensating module for correction (such as a module having the amount of dispersion compensation -100ps/nm) is prepared in order to cope with the case in which the above described case should happen, and is added in order to make a subtle adjustment.

There is also the case in which the input/output level of a dispersion-compensator is made constant, and the loss of the dispersion-compensator must be within a predetermined range regardless of the amount of dispersion compensation. For example, the restriction imposed by the input levels of an O/E, a post-amplifier, etc. In such a case, the loss of the dispersion-compensator will be included within a required range by additionally using an optical attenuator and causing a loss with an intentional shift of an optical axis at the time of a splice, even if the amount of dispersion compensation is changed. It prevents a succeeding device from being influenced.

As a method for connecting a module, a connection by a splice (fusion of fibers), a connection using a connector etc., can be cited. The module itself may be configured so that it can be attached/detached.

Figs.8A through 8D are schematic diagrams explaining modules of a dispersion-compensator. Figs.8A and 8B show variations of an arrangement of modules. Fig.8A shows a variation in which modules are arranged in series or side by side, while Fig.8B shows a variation in which modules are stacked.

Figs.8C and 8D show a connection method in the above cases. Fig.8C shows a method for arranging one of the input and output terminals on one of the opposing sides, and arranging the other of the two terminals on the other of the two sides. Fig.8D shows the structure in which both input and output terminals are arranged on one side. In this case, a module includes a switching circuit, which detects the insertion of a terminal when another module is connected and opens a closed potion, so that the modules become connected.

Figs.9A and 9B exemplify the structures of an optical switch for use in a module of a dispersion-compensator.

Fig.9A shows the implementation in which the insertion of a module is detected in the arrangement shown in Fig.8D. When switches 132 and 133 are closed, an optical path is established between A and C. Light is input to an output port 130, and output from an output port 131. In this implementation, light may be input to the output port 131, and output from the output port 130. Dispersion compensation is made in a portion "A" of the optical path. A portion "C" of the optical path

is a normal path which does not have a dispersion compensation capability.

When another module is connected, the output and input ports of that module are inserted into module insertion detector 135 and 136. The module connection detectors 135 and 136 detect that another module has been connected, and send a signal to a module connection detecting signal processing unit 137. The module connection detecting signal processing unit 137 sends a control signal to the switches 132 and 133 based on this signal. Again, based on this control signal, the switches 132 and 133 switch the optical path so that light travels through A and B.

The switches 132 and 133 may be of any type as long as they can switch an optical path upon receipt of an electric signal. A mechanical switch is available on the market.

Fig.9B exemplifies the specific structure of the module connection detector .

The module connection detector is arranged in an adaptor 139 attached to a connector 138 of the module. In Fig.9B, a projecting portion is arranged as a detector 141. When a connector 140, arranged at the output port of another module, is inserted into the adaptor 139, the projecting portion of the detector 141 moves, turns on a switch 142, arranged at a different location which is electrically connected, and generates a connection detection output. The module connection detecting signal processing unit 137 detects this output, and switches an optical path within the module.

A dispersion-compensating fiber can be used as the implementation of dispersion compensation. In addition, various components are available for the dispersion compensation.

Figs.10A through 10C are schematic diagrams showing the implementation of dispersion compensation other than a dispersion-compensating fiber.

Fig.10A shows a fiber-grating type dispersion-equalizer.

Assume that a grating (a cyclic change of a refractive index) 144 is provided to a fiber 143, and its cycle is changed by degrees. If light is input to the fiber 143, the light is reflected at points which differ depending on wavelength, and returns. Since the light, to which a different delay time is provided depending on the wavelength, returns, it is extracted using a circulator 145, and dispersion-equalized. If the direction of the input to the fiber grating is reversed, a dispersion characteristic of the opposite sign can be obtained.

Fig.10B shows a waveguide type dispersion-equalizer.

Assume that a waveguide 146 is formed using silicon dioxide (SiO_2)on an Si substrate, and a phase shifter 149 is arranged so that the phases of an upper waveguide 147 and a lower waveguide 148 differ from each other. For example, the component of an input optical signal on a long wavelength side propagates along the lower part, while the component on a short wavelength side propagates along the upper part by means of phase adjustment made by a phase shifter 149. A negative dispersion characteristic can be obtained by making the signal propagate along such a waveguide a number of times. Also a dispersion characteristic of the opposite sign can be obtained by adjusting a phase. For example, a thin film heater is used as the phase shifter 149.

Fig.10C shows a resonator type dispersion-equalizer.

A total reflecting mirror 151 and a translucent mirror 150 are opposed. If light is input from the translucent mirror 150, only a light having a certain wavelength according to the distance between both of the mirrors is multiplex-reflected in between, and resonated. Light which is multiplex-reflected a certain number of times proportional to a frequency, and has a frequency in the neighborhood of the resonant wavelength, returns. This light is extracted using a circulator, and a delay time which may differ depending on its frequency (wavelength) is provided and dispersion-equalized. A dispersion characteristic of an opposite direction can be obtained depending on the region to be used at a frequency which is either higher or lower than the resonant frequency.

The tolerance of the amount of dispersion compensation which can secure a required transmission characteristic to be secured can be improved by recognizing chirping provided to an optical signal on a transmitting side as red chirping whose α parameter is positive, arranging a dispersion-compensator in a receiver, adjusting the amount of dispersion compensation of a dispersion-compensator in order to compensate the dispersion of a preceding transmission path in a repeater, and arranging a dispersion-compensator also in a receiver. As a result, the number of menus can be reduced when menus of a dispersion-compensator are set according to a transmission distance.

Furthermore, an optical output can be made higher since the non-linear effect on a transmission path is cancelled by performing the red chirping on the transmitting side.

Claims

1. An optical transmission system which uses in-line amplifiers, and comprises a transmitter (1), repeaters (3, 5), a receiver (7) and transmission paths (2, 4, 6) connecting these components, wherein

    the transmitter (1) performs chirping whose α parameter is positive, for an optical signal; and the transmitter (1), the repeaters (3, 5) and the receiver (7) respectively include a dispersion-compensator (9, 11, 12, 14).

2. An optical transmission system which uses in-line amplifiers, and comprises a transmitter (1), repeat-

ers (3, 5), a receiver (7) and transmission paths (2, 4, 6) connecting these components, wherein

the repeaters (3, 5) and the receiver (7) respectively include a dispersion-compensator (9, 11, 12, 14) having an amount of dispersion compensation for compensating dispersion of a transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7).

3. The optical transmission system according to claim 1, wherein the α parameter is set in a range from "0" to "2".

4. The optical transmission system according to claim 1 or 2, wherein the transmitter (1) includes a dispersion-compensator (9) having a predetermined amount of dispersion compensation.

5. The optical transmission system according to claim 4, wherein the amount of dispersion compensation of the dispersion-compensators (9) included in the transmitter (1) is set to -1200ps/nm or less.

6. The optical transmission system according to claim 1 or 2, wherein the amount of dispersion compensation of the dispersion-compensators (11, 12, 14) respectively included in the repeaters (3, 5) or the receiver (7) is set to -2300ps/nm or less.

7. The optical transmission system according to claim 1, wherein

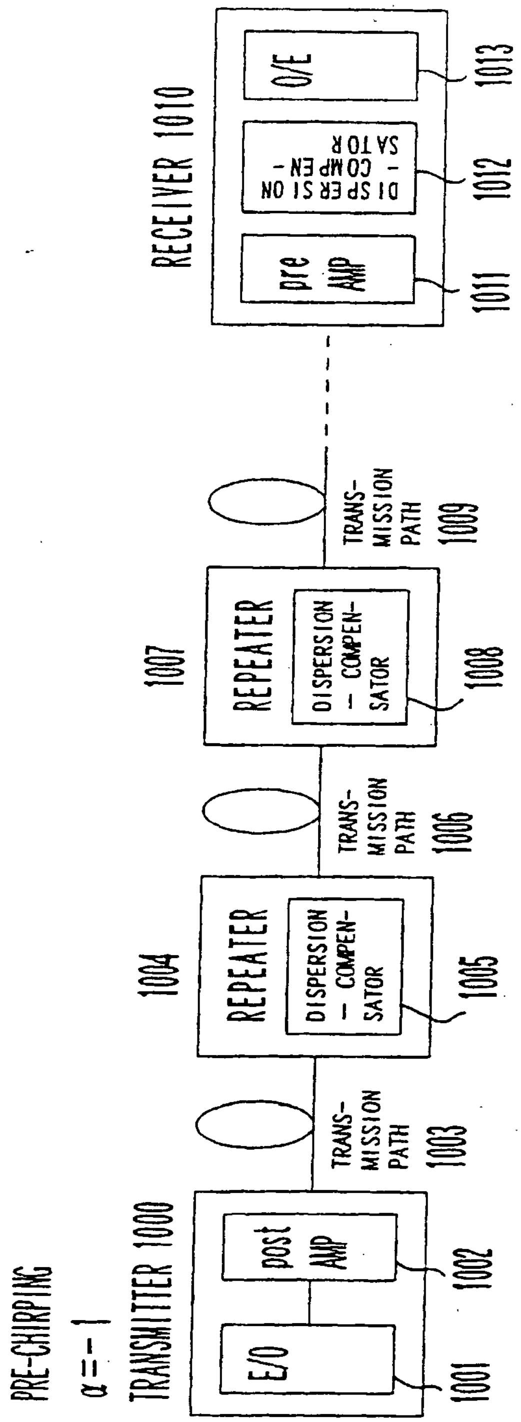
the value of the α parameter is set to approximately +1;
the amount of dispersion compensation of the dispersion-compensator (9) included in the transmitter (1) is set to approximately -600ps/nm;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to 0ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 0 to 22km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -300ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 22 to 38km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -600ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 38 to 58km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -900ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 58 to 78km;
the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) or the receiver (7) is set to approximately -1200ps/nm when the length of the transmission path (2, 4, 6) preceding the repeaters (3, 5) or the receiver (7) is within a range from 78 to 80km;
so that the amount of dispersion compensation of each of the dispersion-compensators (11, 12, 14) included in the repeaters (3, 5) and the receiver (7) is changed according to the length of a preceding transmission path (2, 4, 6).

8. The optical transmission system according to claim 1 or 2, wherein said dispersion-compensator (11, 12, 14) is implemented by using a dispersion-compensating fiber.

9. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a fiber grating.

10. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a waveguide type dispersion-equalizer.

11. The optical transmission system according to claim 1 or 2, wherein the dispersion-compensator (11, 12, 14) is implemented by using a resonator type dispersion-equalizer.



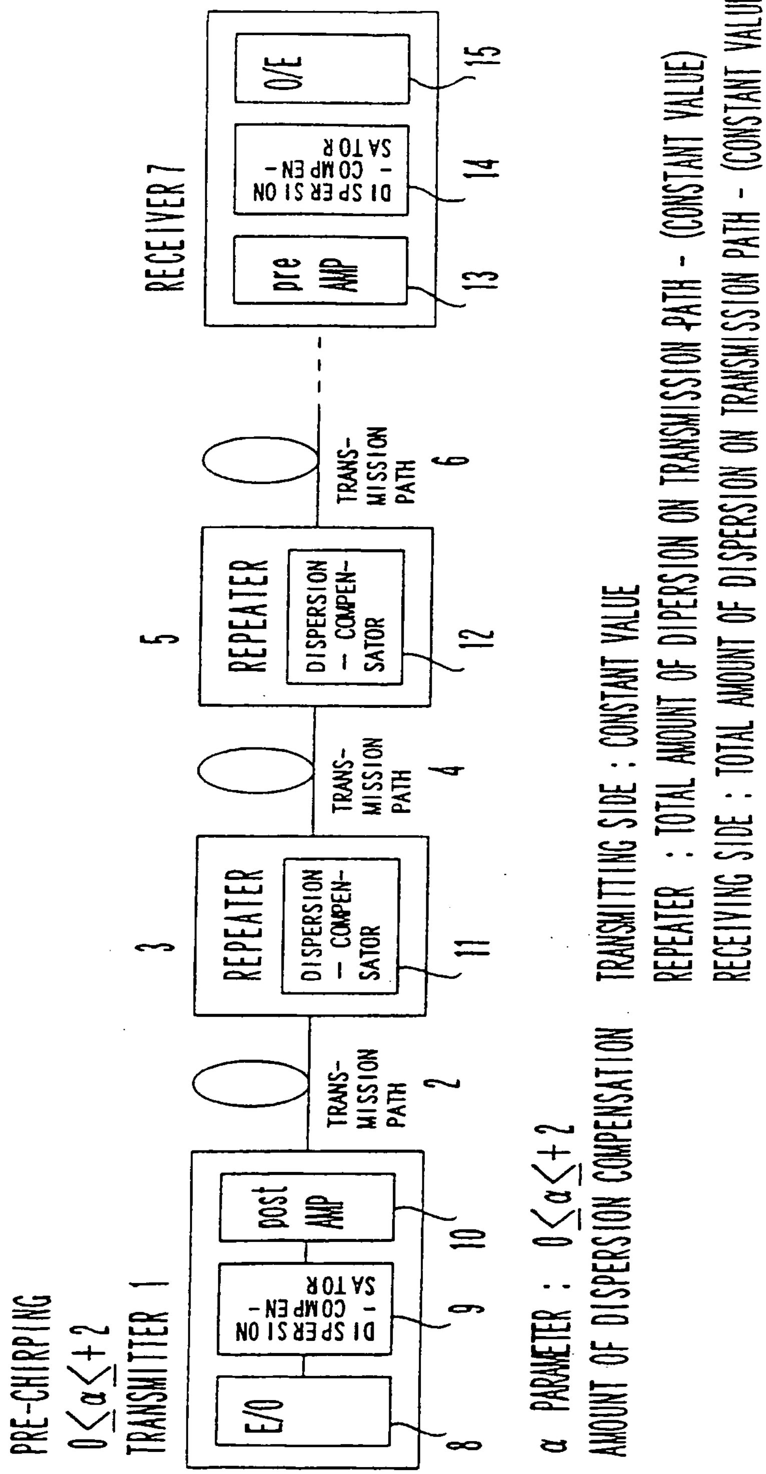
α PARAMETER : -1

AMOUNT OF DISPERSION COMPENSATION TRANSMITTING SIDE : NONE

REPEATERS : TOTAL AMOUNT OF DIPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)

RECEIVING SIDE : TOTAL AMOUNT OF DISPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)

F I G. 1 PRIOR ART


PRE-CHIRPING
0≤α≤+2
TRANSMITTER 1
E/O
DISPERSION - COMPEN- SATOR
post AMP
8
9
10
TRANS-MISSION PATH
2
REPEATER
DISPERSION - COMPEN- SATOR
3
11
TRANS-MISSION PATH
4
REPEATER
DISPERSION - COMPEN- SATOR
5
12
TRANS-MISSION PATH
6
RECEIVER 7
pre AMP
DISPERSION - COMPEN- SATOR
O/E
13
14
15
α PARAMETER : 0≤α≤+2
AMOUNT OF DISPERSION COMPENSATION
TRANSMITTING SIDE : CONSTANT VALUE
REPEATER : TOTAL AMOUNT OF DIPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)
RECEIVING SIDE : TOTAL AMOUNT OF DISPERSION ON TRANSMISSION PATH - (CONSTANT VALUE)

F I G. 2

FIG. 3A

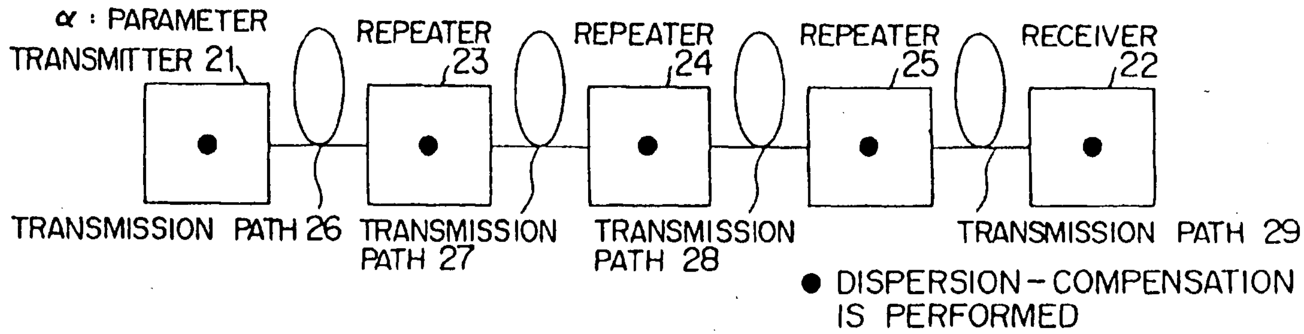

α : PARAMETER
TRANSMITTER 21
REPEATER 23
REPEATER 24
REPEATER 25
RECEIVER 22
TRANSMISSION PATH 26
TRANSMISSION PATH 27
TRANSMISSION PATH 28
TRANSMISSION PATH 29
● DISPERSION-COMPENSATION IS PERFORMED

FIG. 3B

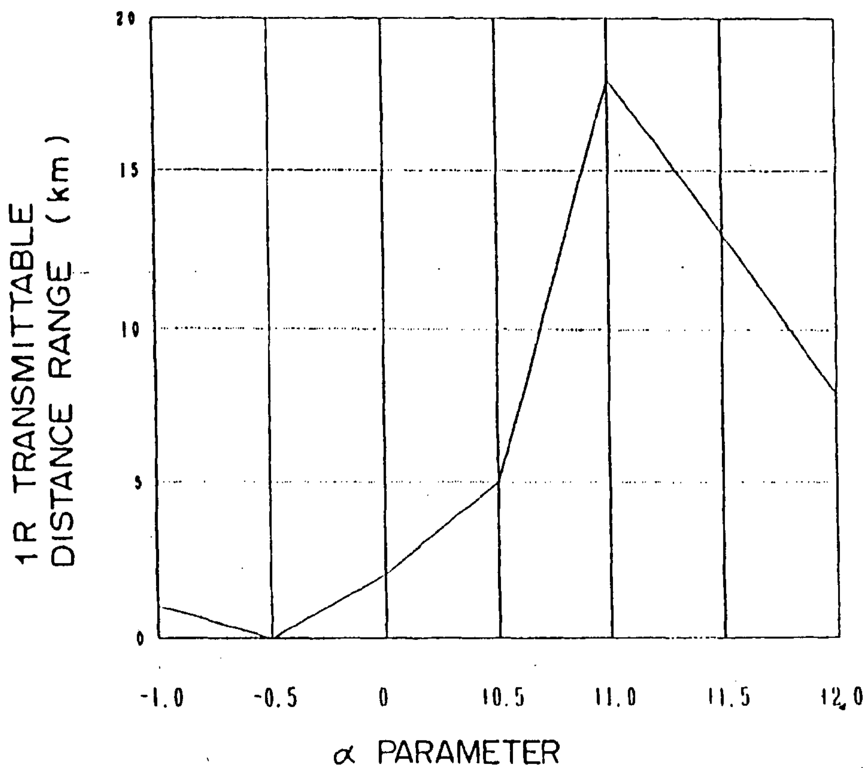

1R TRANSMITTABLE DISTANCE RANGE (km)
20
15
10
5
0
-1.0
-0.5
0
10.5
11.0
11.5
12.0
α PARAMETER

FIG. 4A

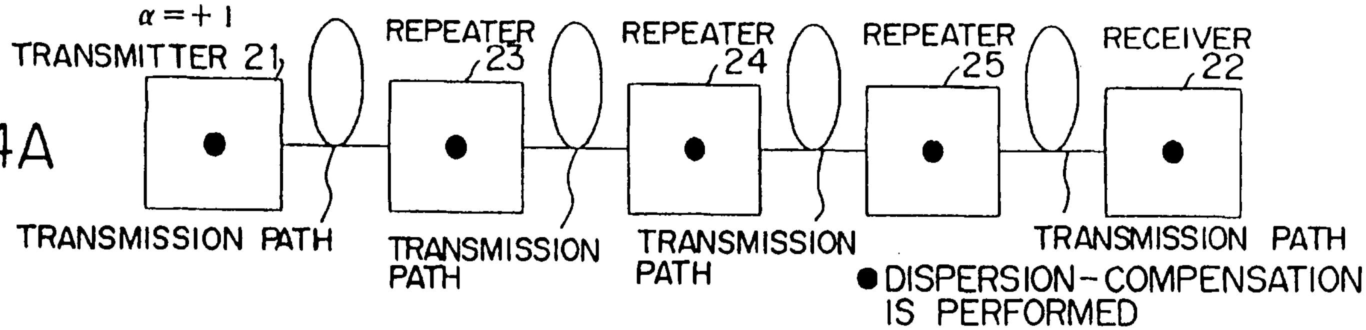
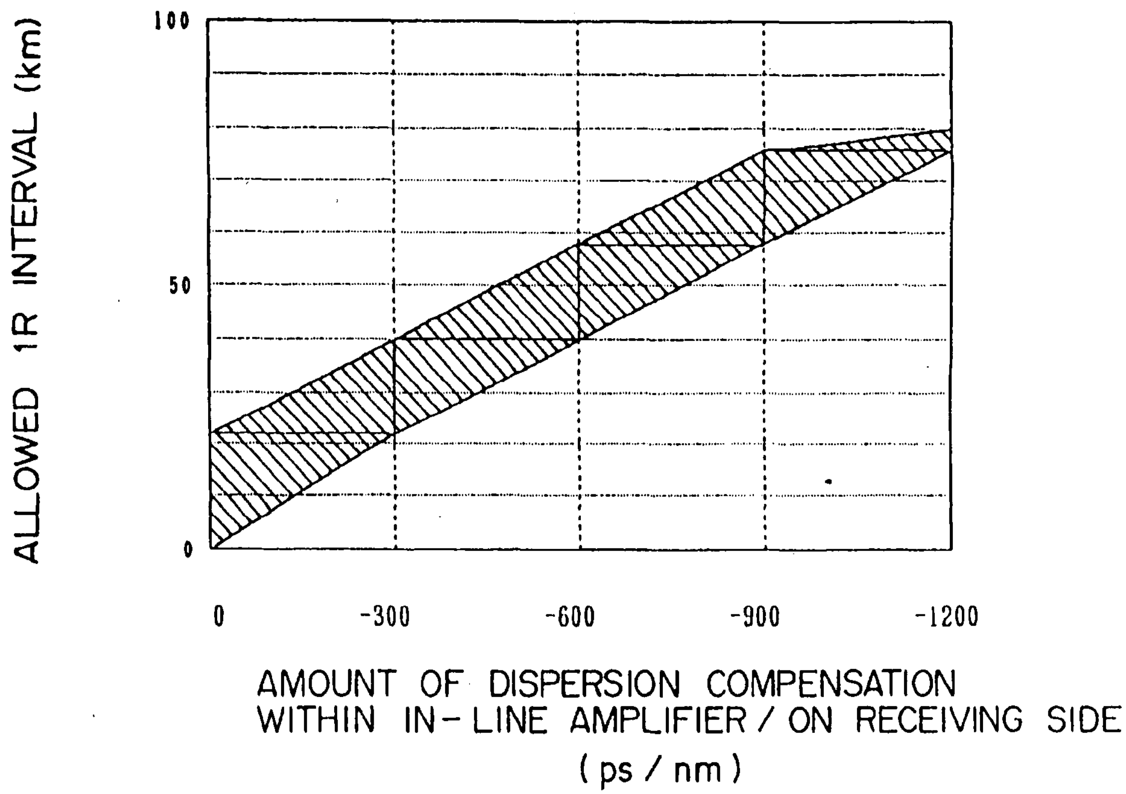
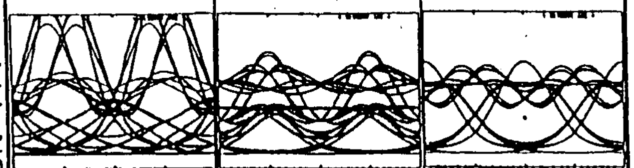
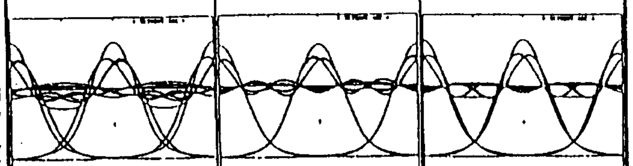

α = + 1
TRANSMITTER 21
REPEATER 23
REPEATER 24
REPEATER 25
RECEIVER 22
TRANSMISSION PATH
TRANSMISSION PATH
TRANSMISSION PATH
TRANSMISSION PATH
● DISPERSION-COMPENSATION IS PERFORMED

FIG. 4B


ALLOWED 1R INTERVAL (km)
100
50
0
0
-300
-600
-900
-1200
AMOUNT OF DISPERSION COMPENSATION
WITHIN IN-LINE AMPLIFIER / ON RECEIVING SIDE
(ps / nm)

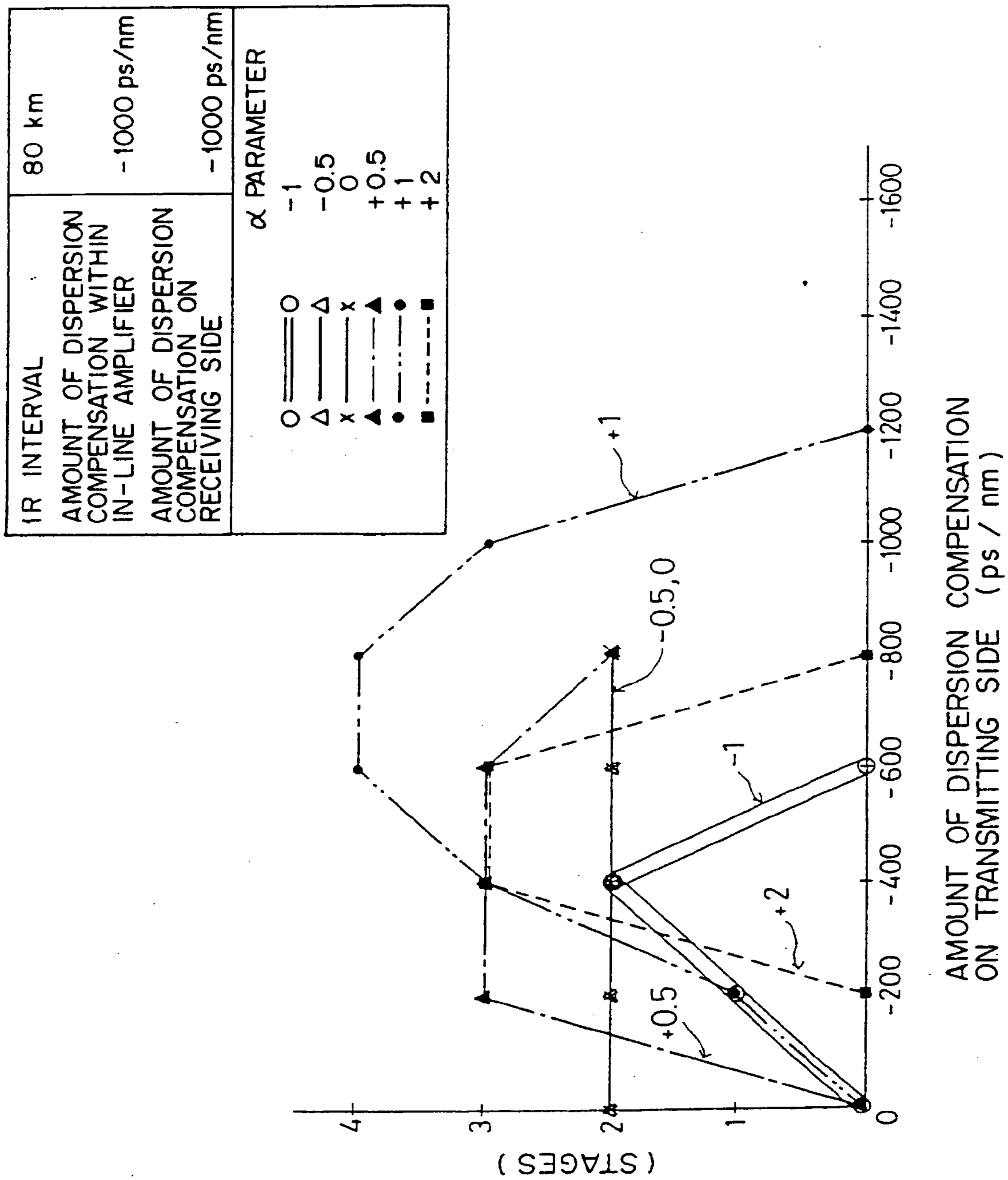
	1R INTERVAL (INDICATED FROM FIRST TO FOURTH PERIOD)		
	10 , 10 , 80 , 80	80 , 80 , 10 , 10	80 , 10 , 80 , 10
COMPENSATION CONDITION (1)			
	2 , 25	0 , 0	78 , 60
	AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER AND ON RECEIVING SIDE : -600 ps/nm x 4 = -2400 ps/nm		
COMPENSATION CONDITION (2)			
	70 , 84	74 , 87	70 , 88
	AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER AND ON RECEIVING SIDE : 10 km : 0 ps/nm , 80 km : -1200 ps/nm TOTAL AMOUNT : -2400 ps/nm		

α PARAMETER	+1
OPTICAL TRANSMISSION POWER	+14 dBm
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE	-600 ps/nm
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER	PARAMETER
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE	PARAMETER
1R INTERNAL	PARAMETER

LEFT SIDE : EYE OPENING IN PHASE DIRECTION
(DETERMINATION CONDITION : 70 % OR HIGHER OK)

RIGHT SIDE : EYE OPENING IN AMPLITUDE DIRECTION
(DETERMINATION CONDITION : 83 % OR HIGHER OK)

FIG. 5



1R INTERVAL
80 km
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER
-1000 ps/nm
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE
-1000 ps/nm
α PARAMETER
-1
-0.5
0
+0.5
+1
+2
NUMBER OF 1Rs (STAGES)
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE (ps / nm)
0
-200
-400
-600
-800
-1000
-1200
-1400
-1600
1
2
3
4
+1
-0.5,0
-1
+2
+0.5

FIG. 6

NUMBER OF 1RS	3
1R INTERVAL	0 ~ 80 km
α PARAMETER	+1
OPTICAL TRANSMISSION POWER	+13~14 dBm
AMOUNT OF DISPERSION COMPENSATION ON TRANSMITTING SIDE	-600 ps / nm
AMOUNT OF DISPERSION COMPENSATION WITHIN IN-LINE AMPLIFIER	0 ~ -1200 ps / nm
AMOUNT OF DISPERSION COMPENSATION ON RECEIVING SIDE	0 ~ -1200 ps / nm

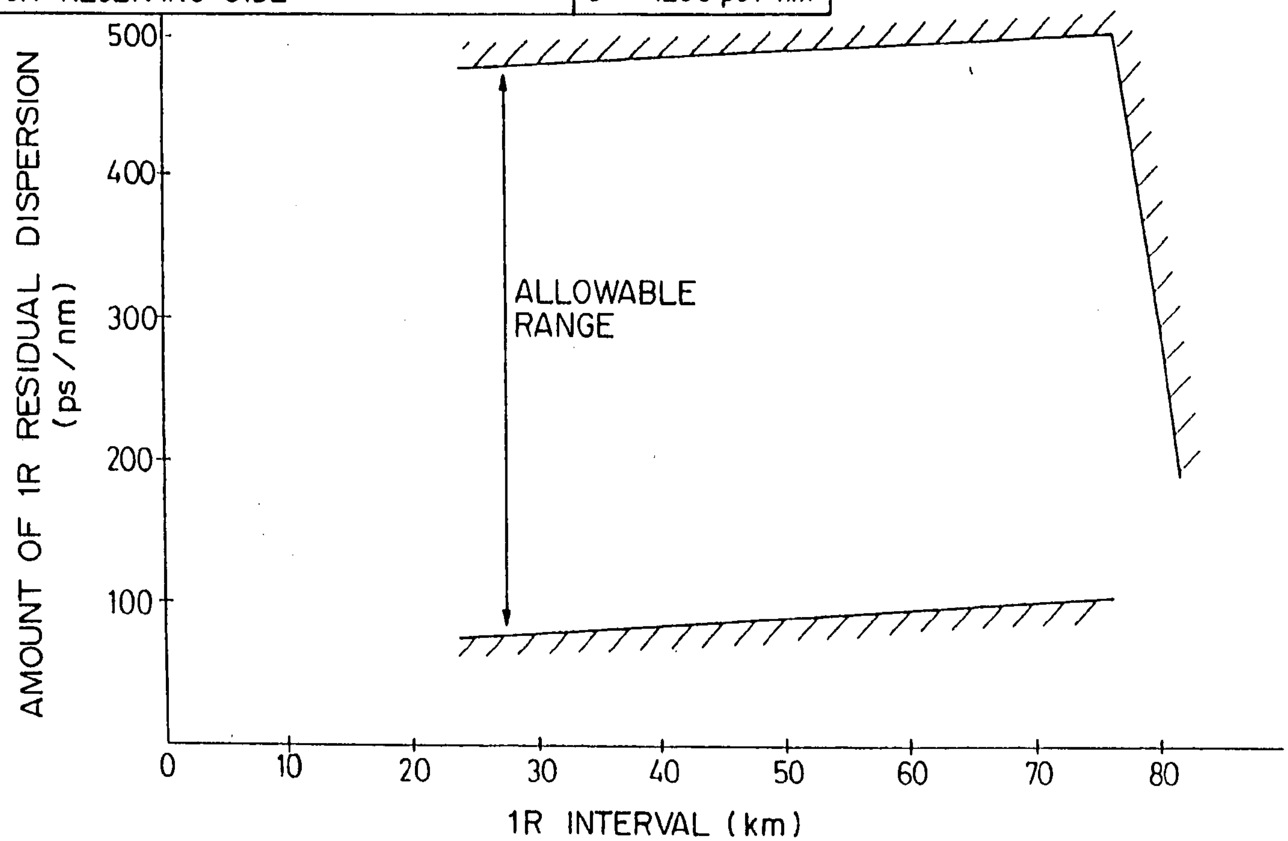


FIG. 7

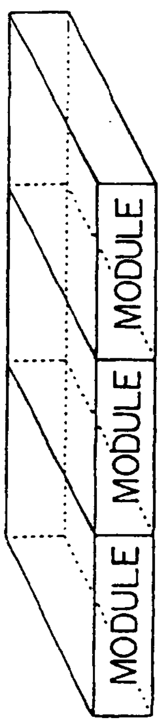


FIG. 8A

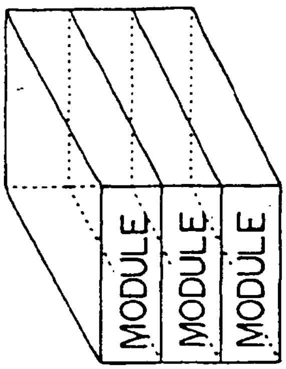


FIG. 8B

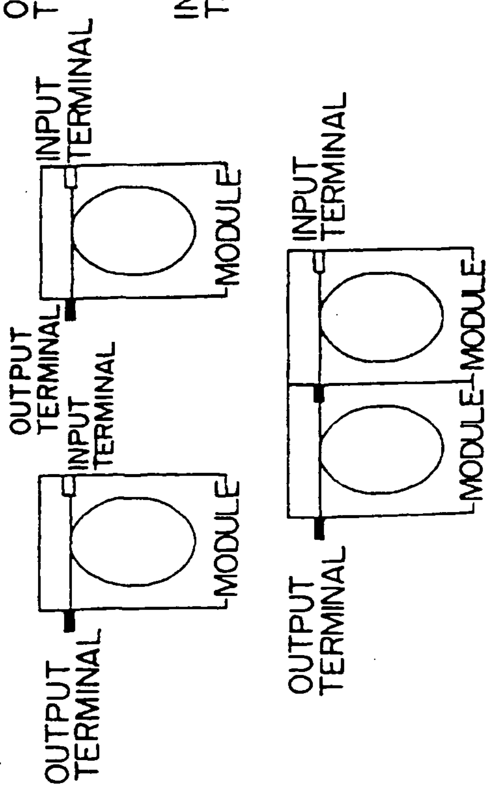


FIG. 8C

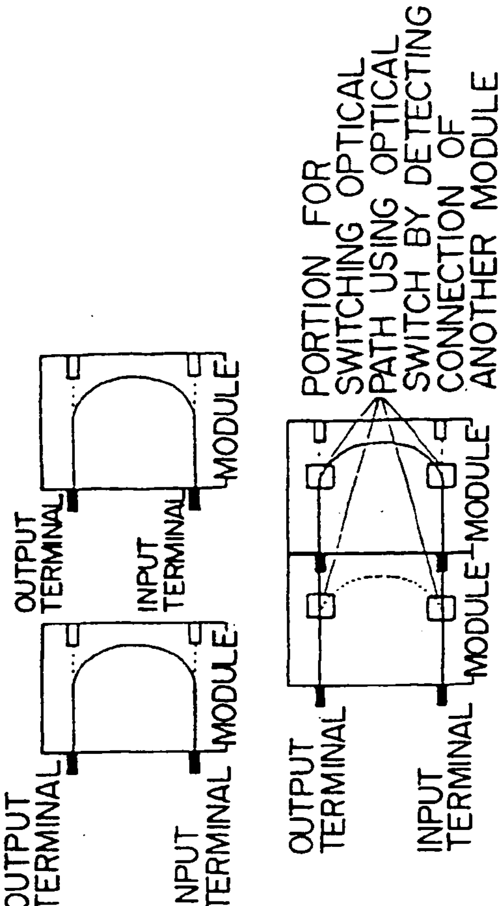


FIG. 8D.

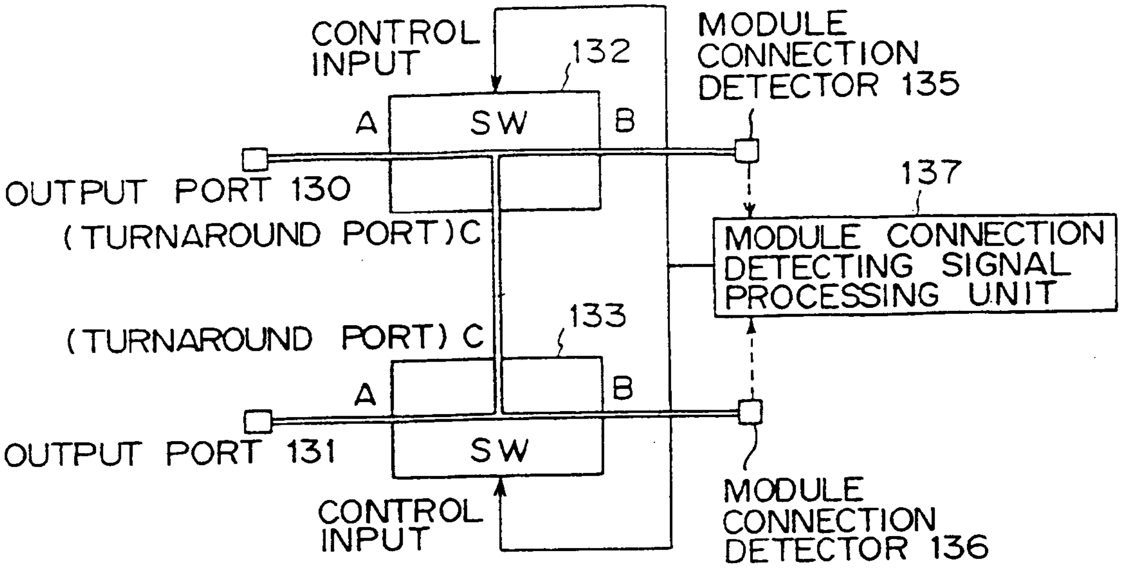

CONTROL
INPUT
132
MODULE
CONNECTION
DETECTOR 135
A
SW
B
OUTPUT PORT 130
137
(TURNAROUND PORT)C
MODULE CONNECTION
DETECTING SIGNAL
PROCESSING UNIT
(TURNAROUND PORT) C
133
A
B
OUTPUT PORT 131
SW
CONTROL
INPUT
MODULE
CONNECTION
DETECTOR 136

FIG. 9A

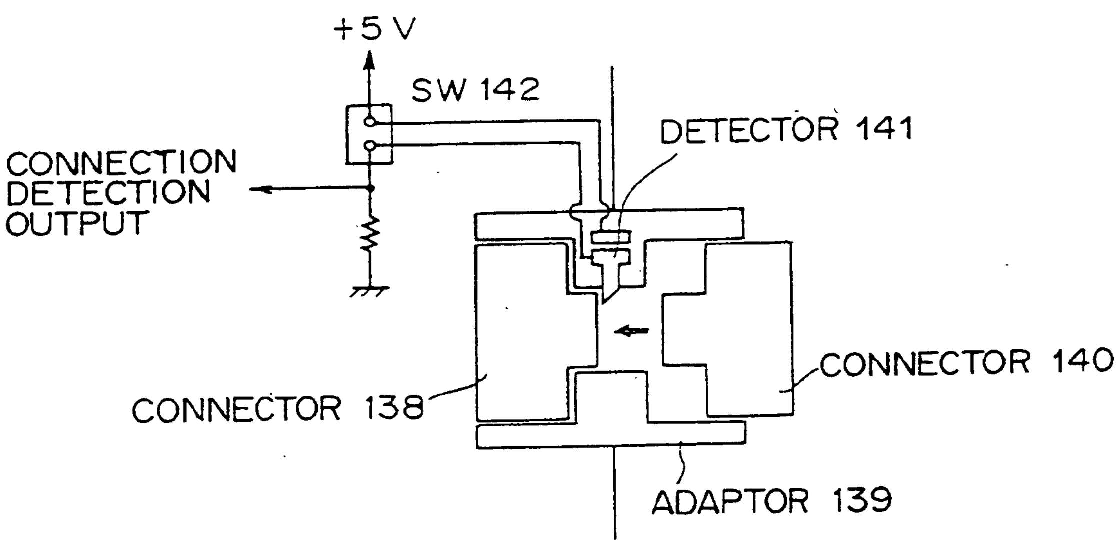

+5 V
SW 142
DETECTOR 141
CONNECTION
DETECTION
OUTPUT
CONNECTOR 140
CONNECTOR 138
ADAPTOR 139

FIG. 9B

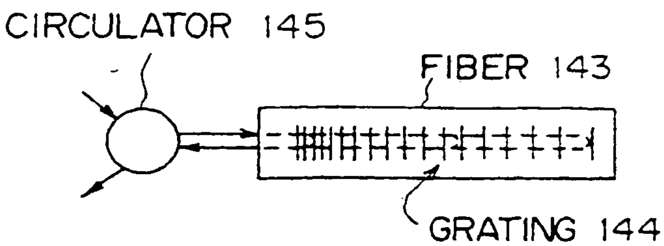


FIG. 10A

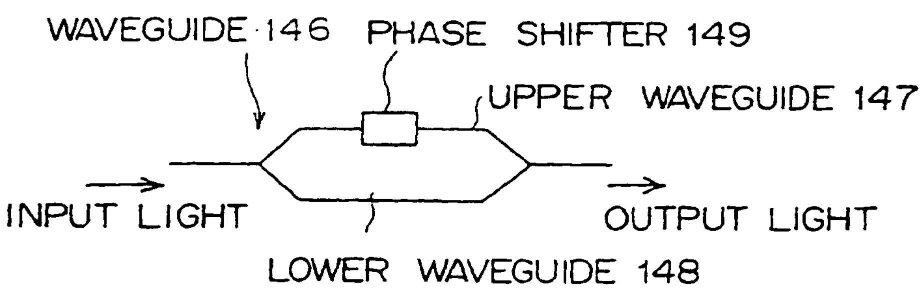


FIG. 10B

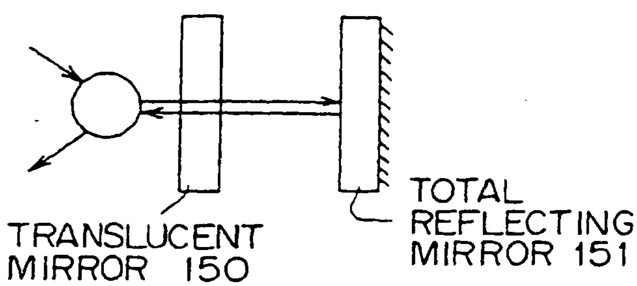


FIG. 10C

(19) Europäisches Patentamt
European Patent Office
Office europ´en des br vets

(11) EP 0 862 285 A3

(12) **EUROPEAN PATENT APPLICATION**

(88) Date of publication A3:
31.10.2001 Bulletin 2001/44

(43) Date of publication A2:
02.09.1998 Bulletin 1998/36

(21) Application number: **97116632.7**

(22) Date of filing: **24.09.1997**

(51) Int Cl.[7]: **H04B 10/18**

(84) Designated Contracting States:
AT BE CH DE DK ES FI FR GB GR IE IT LI LU MC NL PT SE
Designated Extension States:
AL LT LV RO SI

(30) Priority: **27.02.1997 JP 4440797**

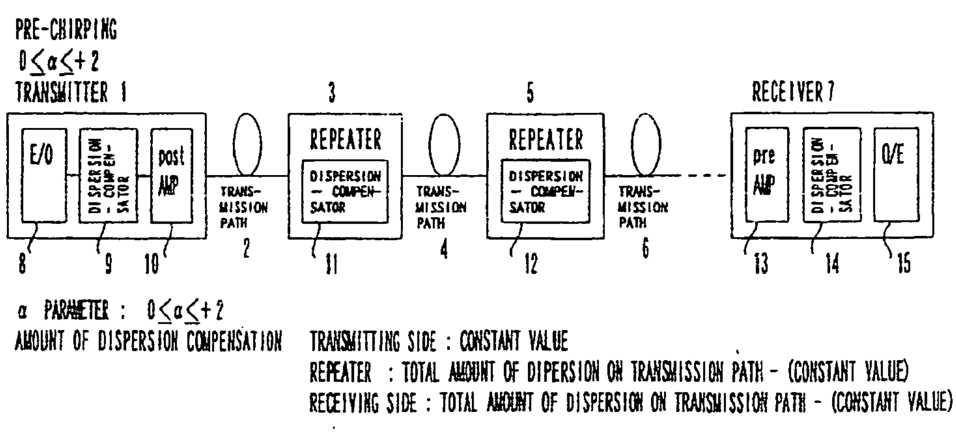
(71) Applicant: **FUJITSU LIMITED**
Kawasaki-shi, Kanagawa 211-8588 (JP)

(72) Inventors:
- **Miyauchi, Akira**
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- **Yamane, Kazuo**
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- **Kawasaki, Yumiko**
  Nakahara-ku, Kawasaki-shi, Kanagawa 211 (JP)
- **Okano, Satoru, c/o Fujitsu H. D. Techn. Ltd.**
  Sapporo-shi, Hokkaido 060 (JP)

(74) Representative:
von Fischern, Bernhard, Dipl.-Ing. et al
Hoffmann - Eitle,
Patent- und Rechtsanwälte,
Arabellastrasse 4
81925 München (DE)

(54) **Optical transmission system using in-line amplifiers**

(57) In a system connecting a transmitter and a receiver using transmission paths and repeaters (in-line amplifiers), red chirping whose α parameter is positive is performed for an optical signal on a transmitting side. Each of the repeaters includes a dispersion-compensator for compensating the amount of dispersion on a preceding transmission path. The amount of dispersion compensation of the dispersion-compensator included in the transmitter is made constant. The dispersion-compensator included in the receiver is arranged in order to compensate the amount of dispersion on a preceding transmission path. A spread of a pulse width on a transmission path can be efficiently compensated by using the compensation capability of the dispersion-compensators and the red chirping on the transmitting side.



F I G. 2

EP 0 862 285 A3

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 97 11 6632

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X Y	EP 0 700 178 A (FUJITSU LTD) 6 March 1996 (1996-03-06) * page 11, line 18 - line 33 * * page 12, line 47 - line 53 * * page 19, line 7 - line 9 * * figures 14,21,43,49 * ---	1,2,4, 8-11 3	H04B10/18
Y	ISHIKAWA G ET AL: "10-GB/S REPEATERLESS TRANSMISSION USING STANDARD SINGLE-MODE FIBER WITH PRE-CHIRPING AND DISPERSION COMPENSATION TECHNIQUES" IEICE TRANSACTIONS ON ELECTRONICS, INSTITUTE OF ELECTRONICS INFORMATION AND COMM. ENG. TOKYO, JP, vol. E78-C, no. 1, 1995, pages 43-49, XP000495082 ISSN: 0916-8524 * page 43, left-hand column, line 38 - right-hand column, line 4 * * figure 2C * ---	3	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	JOPSON B ET AL: "DISPERSION COMPENSATION FOR OPTICAL FIBER SYSTEMS" IEEE COMMUNICATIONS MAGAZINE, IEEE SERVICE CENTER. PISCATAWAY, N.J, US, vol. 33, no. 6, 1 June 1995 (1995-06-01), pages 96-102, XP000545330 ISSN: 0163-6804 * the whole document * ---	1,8-11	H04B
A	FR 2 685 834 A (FRANCE TELECOM) 2 July 1993 (1993-07-02) * page 10, line 14 - line 30; figure 2 * -----	1	

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
THE HAGUE	5 September 2001	Cochet, B

CATEGORY OF CITED DOCUMENTS

X : particularly relevant if taken alone
Y : particularly relevant if combined with another document of the same category
A : technological background
O : non-written disclosure
P : intermediate document

T : theory or principle underlying the invention
E : earlier patent document, but published on, or after the filing date
D : document cited in the application
L : document cited for other reasons

& : member of the same patent family, corresponding document

EPO FORM 1503 03.82 (P04C01)

ANNEX TO THE EUROPEAN SEARCH REPORT ON EUROPEAN PATENT APPLICATION NO. EP 97 11 6632

This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
The European Patent Office is in no way liable for these particulars which are merely given for the purpose of information.

05-09-2001

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
EP 0700178 A	06-03-1996	JP 8321805 A	03-12-1996
		US 5991477 A	23-11-1999
		US 5870213 A	09-02-1999
		US 5717510 A	10-02-1998
		US 5909297 A	01-06-1999
		US 5815294 A	29-09-1998
		US 5754322 A	19-05-1998
		US 5896217 A	20-04-1999
		US 5760937 A	02-06-1998
FR 2685834 A	02-07-1993	GB 2263598 A,B	28-07-1993
		JP 5276121 A	22-10-1993
		US 5373382 A	13-12-1994

EPO FORM P0459

For more details about this annex : see Official Journal of the European Patent Office, No. 12/82